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PROBLEMS OF SPACE BIOLOGY, VOL. 13
Prolonged Limitation of Mobility and Its Influence on the Human Organism

A. M. Genin and P. A. Sorokin, Editors

"Nauka" Press, Moscow, 1969

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Prolonged Limitation of Mobility and Its Influence on the Human Organism

A. M. Genin and P. A. Sorokin, Editors

Translation of "Problemy Kosmicheskoy Biologii, Tom XIII. Dlitel'noye ogranicheniye podvizhnosti i yego vliyaniye na organism cheloveka." "Nauka" Press, Moscow, 1969

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ANNOTATION

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Problems of Space Biology, Vol. XIII. Prolonged Limitation of Mobility and Its Influence on the Human Organism. "Nauka" Press, 1969.

This collection presents the results of a complex clinical-physiology study of healthy individuals who were confined strictly to bed for many days. It describes in broad terms the influence of prolonged limitation of mobility on the organism's various functional systems, tolerance of orthostatic tests and load factors. The effects of special sets of physical exercises and certain other measures to prevent unfavorable shifts in the organism under the influence of prolonged confinement to bed are examined.

This collection will be of interest to a broad range of clinicians and physiologists concerned with the problem of prolonged limitation of mobility.

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*Numbers in the margin indicate pagination in the foreign text.

FOREWORD /5

The living conditions and degree of comfort associated with modern civilization have sharply reduced the motor activity of man and made hypodynamia one of the most important problems of the century.

Prolonged limitation of mobility, or hypodynamia, is of interest from at least three aspects.

Conditions of strict hypodynamia are characteristic for the clinical treatment of many illnesses. The various forms of cardiovascular disease, injuries to the nervous system, and certain types of traumas require strict confinement of the patient to bed for periods that may run into the weeks and months. This naturally gives rise to the question of designing rational treatment on the basis of conceptions of the favorable influence of rest on the particular injured organ or system and the deconditioning — in the broad sense of the word — influence of hypodynamia on the organism as a whole.

Among healthy individuals, strict hypodynamic regimes may obviously be imposed on those who make long spaceflights. Even with systematic physical exercise under the conditions of weightlessness, it is extremely difficult to make up the muscular-load deficit that results from cessation of postural-musculature activity. At the same time, weightlessness has a specific deconditioning effect on the cardiovascular system, since the hydrostatic /6
blood pressure, which imposes a kind of load on the heart and blood vessels in the standing position on the earth, vanishes along with weight. Obviously, evaluation of the probable consequences of prolonged weightlessness is of very great prognostic importance for manned spaceflight.

Finally, as we have already noted, technical progress places increasing numbers of persons under conditions that create the prerequisites for relative hypodynamia. Despite the extensive propaganda attention given to physical culture and sports, a disproportion arises and grows between mental activity, which is inevitably on the increase, and physical activity, which becomes less and less mandatory. As yet, very little study has been devoted to the significance of this shift toward cerebral activity from the standpoint of physiology and pathology.

Obviously, only "pure" experiments to study the influence of some variant of controlled hypodynamia on healthy individuals can give more or less adequate answers to the questions that arise in these aspects. In recent years, in connection with the development of manned-spaceflight problems, such experiments have been carried out in considerable numbers. However, the papers in which the results of these experiments are set forth generally report the influence of hypodynamia only on isolated functional systems of the organism or the tolerance of certain specific flight factors. In fact, no attempt has been made to describe and generalize the entire complex of changes that arise under the influence of prolonged and relatively strict hypodynamia.

To a considerable degree, the present volume of "Problems of Space Biology" will fill this gap. The basic material of the collection reflects the results of studies made on 16 healthy subjects, who were strictly confined to bed for 70 days. The researches were very broad in scope and included more thoroughgoing study of the state of the cardiovascular system, energy metabolism, nutrition, the functions of the central nervous system, the /7
supporting-and-motor apparatus, certain analyzers, mental activity, and a number of biochemical indicators.

Thus, the material presented in the collection is interesting not only for the scale of the experiment and the duration of the hypodynamia. It permits characterization of hypodynamia as a kind of disturbance that results in readjustment of all of the major functional systems of the organism. This readjustment can hardly be regarded as a simple lowering of functional capabilities and conditioning to ordinary loads. Depending on the degree to which mobility is limited and the individual peculiarities of the human subject, bed rest may emerge as a factor that provokes the development of certain pathological states or causes shifts bordering on the pathological.

The objectives of the experiments under discussion here also included evaluation of methods recommended against the unfavorable influence of hypodynamia on the human organism. Physical exercises, which the subjects carried out in the horizontal position, periodic compression of the extremities with air cuffs, and a range of pharmacentical preparations were tested as preventive measures. Professors A.M. Genin, P.A. Sorokin, and their colleagues were successful in formulating the complex combined studies.

It can be hazarded that the material published in this collection will prove helpful to a broad range of physiologists and clinicians interested in the problem of prolonged restriction of mobility and to investigators working on the physiological aspects of spaceflight.

Professor O. Gazenko
Corresponding Member of the USSR Academy of Sciences

TABLE OF CONTENTS

Foreword v

A.M. Genin and P.A. Sorokin. Prolonged Limitation of Mobility as a Model of the Influence of Weightlessness on the Human Organism. 1

P.A. Sorokin, A.M. Genin, M.I. Tishchenko, P.V. Vasil'yev, R.I. Gismatulin, and I.D. Pestov. Organizational and Methodological Principles for the Conduct of Prolonged Hypodynamia Researches. 8

P.A. Sorokin, V.V. Simonenko, and B.A. Korolev. Clinical Observations in Prolonged Hypodynamia 15

A.D. Voskresenskiy, B.A. Korolev, and M.D. Ventsel'. Changes in Electrocardiogram and Statistical Structure of Cardiac Rhythm in the Course of Confinement to Bed . . 26

V.V. Simonenko. Hemodynamic Changes During Prolonged Hypokinesia According to Mechanocardiographic Data. 34

A.P. Pekshev. Hemodynamic Changes During Prolonged Hypokinesia on the Basis of the Dye-Dilution Method 43

M.I. Tishchenko, B.A. Korolev, V.A. Degtyarev, and B.F. Asyamolov. Phase Changes in the Cardiac Cycle During Prolonged Hypodynamia According to Polycardiographic and Kinetocardiographic Data. 52

I.G. Krasnykh. Influence of Prolonged Hypodynamia on Heart Size and the Functional State of the Myocardium 58

M.I. Mikhasev, V.I. Sokolkov, and M.A. Tikhonov. Certain Peculiarities of External Respiration and Gas Exchange During Prolonged Hypodynamia. 66

M.S. Seregin, I.G. Popov, Z.N. Lebedeva, O.A. Goryacheva, S.A. Kamforina, P.V. Oblapenko, P.F. Vokhmyanin, and L.A. Andreyeva. Nutrition and Metabolism During Prolonged Hypodynamia. 73

I.G. Krasnykh. Mineral Saturation of Bone Tissue Under Conditions of Prolonged Hypodynamia. 89

I.I. Ivanov, B.F. Korovkin, and N.P. Mikhaleva. Investigation of Certain Biochemical Blood Serum Indicators During Prolonged Hypodynamia 96

T.A. Orlova. Urea Content in the Blood During Prolonged Limitation of Mobility. 106

Ye.I. Dorokhova. Coagulability of Blood During Prolonged Hypodynamia According to Thromboelastographic Data . . . 108

B.A. Chukhlovin and S.A. Burov. Resistance to Infection Under Conditions of Hypodynamia 113

G.D. Yefimenko. Functional State of the Central Nervous System During Prolonged Hypodynamia. 121

A.G. Panov, V.S. Lobzin, and V.A. Belyankin. Changes in the Functions of the Nervous and Muscular Systems under the Influence of Prolonged Hypodynamia 133

V.S. Gurfinkel', Ye.I. Pal'tsev, A.G. Fel'dman, and A.M. El'ner. Changes in Certain Human Motor Functions After Prolonged Hypodynamia. 148

V.G. Skrypnik. Changes in the Biochemical Peculiarities of Walking under the Influence of Hypodynamia According to Ichnographic Data. 160

V.P. Bogachenko. State of Psychic Activity in Subjects During Prolonged Confinement to Bed. 170

V.L. Marishchuk, T.T. Dzhamgarov, Yu.K. Dem'yanenko, V.P. Stupnitskiy, and B.S. Khvoynov. Stability of Psychic Functions During Prolonged Confinement to Bed. 175

K.L. Khilov, A.Ye. Kurashvili, and V.P. Rudenko. Influence of Prolonged Hypodynamia on the State of the Vestibular Analyzer 184

N.T. Drozdova and O.P. Nesterenko. State of the Visual Analyzer During Hypodynamia. 192

A.V. Yeremin, V.V. Bazhanov, V.L. Marishchuk, V.I. Stepantsov and T.T. Dzhamgarov. Physical Conditioning for Man Under Conditions of Prolonged Hypodynamia. 196

V.G. Voloshin, I.D. Pestov, and B.F. Asyamolov. Occlusion Conditioning under the Conditions of Prolonged Hypodynamia. 205

P.V. Vasil'yev and B.Yu. Lapinskaya. Results From Use of Medication in Individuals Subject to Prolonged Hypokinesia. 211

G.S. Kalin and V.G. Terent'yev. State of Nervous-System Functions During Aftereffects of Hypodynamia 219

A.V. Beregovkin, P.V. Buyanov, A.V. Galkin, N.V. Pisarenko, and Ye.Ye. Sheludyakov. Results of Investigations of the Cardiovascular System During the Aftereffect of 70-Day Hypodynamia. 227

Ye.G. Ryabkova and I.I. Shantyr'. Regional Arterial Oscillographic Indices During Hypodynamia 234

I.D. Pestov, M.I. Tishchenko, B.A. Korolev, B.F. Asyamolov, V.V. Simonenko, and A.Ye. Baykov. An Investigation of Orthostatic Stability After Prolonged Hypodynamia. . . . 238

A.R. Kotovskaya, R.A. Vartbaronov, and S.F. Simpura. Change in Load-Factor Tolerance After 70 Days of Hypodynamia. 248

A.M. Genin, P.A. Sorokin, G.I. Gurvich, T.T. Dzhamgarov, A.G. Panov, I.I. Ivanov, and I.D. Pestov. Basic Results from Studies of the Influence of 70-Day Hypodynamia on the Human Organism. 256

PROLONGED LIMITATION OF MOBILITY AS A MODEL OF THE INFLUENCE OF WEIGHTLESSNESS ON THE HUMAN ORGANISM

/9

A.M. Genin and P.A. Sorokin

ABSTRACT: The paper examines experimental approaches to evaluation of the biological effects of prolonged weightlessness. Laboratory simulation of weightlessness, with prolonged bed rest as an example, is defended. The initial conception that formed the basis for the 70-day hypodynamia study is formulated.

With the development of space travel, it has become necessary to reevaluate the biological role of earth gravity and determine the possible influence of the weightless state on the organism. It has long been known that gravity has left its imprint on the evolution, structure, functions, and behavior of living organisms. However, it was found during preparations for the very first space flights that science is essentially not in a position to answer the question as to whether gravity is a necessary condition for normal vital activity. Only after a series of experiments with geophysical rockets and biological and manned satellites, during which the effects of weightlessness on animals and humans were studied, were the direst of the predictions laid to rest. It was also possible at the same time to gain some idea of the primary reactions of the organism to the absence of gravity and the trends of their subsequent development over orbital flights lasting 1-2 weeks. The extensive literature that has been devoted to exposition and interpretation of flight-experiment results (Gazenko, Gyurdzhian, 1967; Parin et al., 1967; Berry, Catterson, 1967) examines as the basic weightlessness-connected mechanisms that produce changes:

- modified conditions of motor activity,

- disappearance of the hydrostatic blood-column pressure on the walls of the vascular lumen,

- changes in the activity of the afferent systems.

It is apparently the combination of such primary effects of weightlessness that gives rise to changes in water-salt, hormonal, and energy metabolisms and in the cardiovascular, respiratory, and /10 digestive systems, the blood system, the supporting-and-motor apparatus, analyzer functions, and the central nervous system that

have been reflected to one degree or another in manned orbital flights. Experience already accumulated indicates that these shifts may, in turn, result in deterioration of the cosmonaut's general condition and fitness for work, and a decrease in his resistance to the factors operating in a real spaceflight. In particular, there may be substantially reduced tolerance to the load factors encountered during the return of the spacecraft to the earth and to earth gravity after the return.

The need to establish longer-range tendencies in the development of these changes has now become perfectly clear. Will they become steadily aggravated as the times of spaceflights become longer, or will they stop after reaching a certain limit, allowing the organism to come out onto a new stable level adequate to activity in zero-gravity conditions? It would be an extremely important advance if we could clarify the question as to the reversibility of the changes that arise in this case. The cosmonaut is a man of our planet, and after carrying out his space mission, he must return to it fit to live and work in an environmental habit that he managed to break during his flight. Consequently, the problem of developing a set of measures directed toward maintenance, under the conditions of spaceflight, of a state of the organism consistent with readiness to live and work in earth gravity also becomes extremely urgent.

Since it is impossible to reproduce true weightlessness for extended periods on the ground, the question arises as to what experimental approaches might be used to evaluate the biological effects of prolonged weightlessness and solve other associated problems.

In this context, it will be helpful to pause to analyze certain fundamentally possible approaches.

The first of them may be based on manned spaceflights of progressively increased duration. Then the data obtained during the relatively short flights could serve as a point of departure for inferences as to the possibility and safety of the next flight, which would be somewhat longer. The good sense of such an approach is obvious. In essence, it has already been acknowledged, as indicated by the actual ventures that man has made into cosmic space. However, it has shortcomings in the lack of advance information, a certain element of risk, a certain lag in the design of protective measures, and its high cost in time and money.

Another approach that is possible in principle consists of /11
conducting research with biological satellites, on which various biological entities, such as dogs, monkeys, and certain laboratory animals, could be sent on long spaceflights. A certain amount of experience has now also been accumulated as regards use of this approach. It should be noted that it is not only justified, but even indispensable in application to certain strictly defined

problems. Resolution of questions as to the survival, growth, development, and behavior of various biological objects in zero gravity is of quite independent importance. However, even when the most highly organized laboratory animals are used, it is necessary to consider the difficulty of interpreting the data obtained as they apply to man. On the one hand, there is every reason to assume that the biological importance of the gravitational factor for the human organism and, for example, such laboratory animals as dogs, will not be the same. The vertical orientation of the organism in the gravitational field that is specific for man is obviously an extremely important circumstance, since the gravity vector acts along the body's longitudinal axis in this case. This has determined quite specific peculiarities in the regulation of vascular and muscle tone and other related functions, which are precisely those that suffer most in weightlessness. The horizontal orientations of laboratory animals, with respect to which the gravity vector acts transversely, evidently makes them relatively more indifferent to the zero-gravity state.

On the other hand, the conditions under which long-term automated experiments are carried out aboard biological satellites are inevitably associated with a number of technical difficulties that make it hard to care for the animals and inevitably require that the experiment be compounded by additional stress disturbances whose significance can far from always be taken into account by setting up control experiments on the earth. But even if it is possible to separate the useful information from artifacts on an adequate volume of experimental material, it will still not be possible to apply the data directly to man.

This also leaves practically unsolved the problem of preventing the disturbances to which the human may be subject in a long flight.

In other words, the conduct of biological research on animals in outer space must be regarded merely as a supplementary measure on the way to ensuring human safety in long spaceflights.

It appears that the most fruitful and realistic approach would be that based on study of human reactions in laboratory simulation of certain effects that are characteristic for prolonged sojourns in zero gravity. Since, as we have already stated, weightlessness affects the organism chiefly through motor-activity peculiarities, the drop in hydrostatic blood pressure, and changes in afferent-system activity, it will be expedient to consider the possibility of experimental simulation of these primary effects. /12

The influence of earth gravity on the structure and function of the supporting-and-motor apparatus is perhaps most obvious. The skeleton and muscular system are formed, reflex regulation of muscle tone is established to sustain posture, the stereotype

of motor activity is developed and the activity of the internal organs, metabolic processes, and the nervous and hormonal systems is organized for the ecologically conditioned volume of muscular work — all in accordance with the habitual orientation of the organism in the gravitational field. The absence of gravity changes the conditions of motor activity substantially. The weight load on the supporting structures (skeleton, ligaments, joints, internal surfaces of cavities, etc.) is removed. There is no need for active maintenance of posture and, consequently, no need for tonic stressing of the postural musculature. To move about, it is necessary to overcome only the body's inertia, and not its weight. All these factors cannot but result in lowered expenditure of energy in muscle contractions. The oxygen-transport requirements and hence cardiac activity are reduced as a result.

The effects of disuse appear and reduce the masses of the muscles, their strength, the organism's endurance and have a chain of other interrelated consequences. It should be noted that in principle, the state described here is quite well known both in clinical practice and in the experience of the athletic trainer. Such terms as quiescence, limited mobility, hypodynamia, and certain others are used to connote it. In our opinion, the term "hypodynamia" appears most general and has recently been used relatively more often. Attempts to use hypodynamia to simulate the modified conditions of motor activity in zero gravity are now being undertaken on a rather broad scale. The reactions of the organism both to quite strict limitation of mobility, right up to the use of various immobilization methods and plaster-casting (Deitrick, et al., 1948) and to confinement under conditions of relative quiescence in chairs or in bed (Lamb, et al., 1964; Buyanov, 1964) are coming under study. According to Lamb (1965), the state of reduced motor activity that is reproduced in model experiments of this type results in a decrease in orthostatic stability and physical endurance and in the development of other changes characteristic of weightlessness, regardless of the subject's position — lying or sitting. On the basis of these data, /13
Lamb is inclined to regard hypodynamia as the most basic cause of the disturbances associated with weightlessness, and adequate muscular activity as the most effective prophylactic measure against them.

Contrary to the opinion of this author, Graveline (1962) takes the view that the only reaction by which the biological system reacts to gravitational forces is the distribution of the liquid medium in the organism. The absence of gravity eliminates operation of the hydrostatic factor on the blood vessels of the body's lower half and results in a relative decrease in the volume of blood in them. The central blood exchange increases accordingly. Henry and Gauer (1956) were the first to describe the mechanism of the changes in water-salt metabolism that arise under these conditions and result in a reduction of the plasma volume in the organism, a rise in the hematocrit value, condensation of the

blood, and a decrease in its total volume. The fact that most cosmonauts have shown a decrease in body weight and dehydration of the organism after completing spaceflights can apparently be explained within the framework of the theory under consideration. It is also known that a decrease in the volume of circulating blood and dehydration of the organism are detrimental to tolerance of orthostatic disturbances, physical work, and load factors even if they are reproduced experimentally, as by limiting water intake (C. Di Giovanni, Birkhead, 1964; Greenleaf, et al., 1966). However, since the decrease in the hydrostatic component of blood pressure that is characteristic for weightlessness is accompanied not only by disturbances of water-salt metabolism, but also by a change in regulation of vascular tone, it becomes obvious that the experimental model must also cover this aspect of the effects of zero gravity on the organism. In view of this fact, it must be acknowledged that the dehydration caused simply by limiting water intake or subjection to high temperature is not a fully adequate model. Experimentally produced conditions that would lower the hydrostatic blood pressure and redistribute the blood would be much more to the point. These requirements are met by restriction to the horizontal position or immersion in a liquid whose density is closely similar to that of the body.

In the case of the horizontal position, in which the gravity vector is perpendicular to the body's longitudinal axis, the role of the hydrostatic component of blood pressure on the vessels is reduced substantially. The accustomed variations in stimuli to the vessel-wall baroreceptors that result from the hydrostatic-pressure fluctuations in walking, running, jumping, etc., vanish at the same time. It may therefore be assumed that the conditions /14 of blood circulation in the horizontal position simulate weightlessness quite well.

When the organism is immersed in a liquid whose density is equal to that of the body, the hydrostatic action of the blood column is compensated by an equivalent counterpressure on the outer walls of the vessels. Another consequence is a redistribution of the blood, consisting in an increase in its central volume. If the body is lowered into the immersion medium up to the neck and the subject breathes atmospheric air, the scale of this redistribution increases even further. The pressure in the lungs is lower than the ambient pressure, and the effect is to draw blood into the thorax. As a result, the reactions that arise when the immersion model is used are more conspicuous than in the case of bed rest and, in any event, intervene earlier. This fact determines the field in which it can be applied to greatest advantage. Shifts in the water-salt exchange, orthostatic stability, and physical fitness for work can be reproduced quite easily with the immersion model, and then various types of corrective measures can be tested. However, the immersion model is evidently unsuitable for resolution of the question as to the influence of prolonged weightlessness on the organism.

The question is somewhat more complex when we come to experimental simulation of the reactions that arise in zero gravity in the activity of the afferent systems. While a decrease in the proprioceptive afferent background can be produced to a greater or lesser degree by limiting mobility, by reducing the weight load on the supporting surfaces in the horizontal position or in the immersion medium, functional exclusion of such important gravireceptors as the vestibular apparatus is a difficult problem to solve. Proposals for the use of rotation about an axis perpendicular to the gravity vector (J. Muller, 1958) have not yet come into extensive use in experimental practice. The use of surgical deafferentation (Wunder, 1965) can, for obvious reasons, be recommended only in animal experiments. But even in this case it is impossible to simulate the complex range of interrelationships that come into play under the conditions of actual weightlessness. All this naturally limits the possibilities for use of the methodological approaches by means of which it is now possible to simulate the weightless state on the ground, but does not render them altogether useless.

On the basis of the above, we may conclude that the problems of experimental study of the effects of prolonged weightlessness are best served by a model in which hypodynamia is combined with the horizontal position. This model reproduces quite well the primary reactions associated with many aspects of weightlessness and apparently contains no manifest side effects capable of substantially distorting the course of the basic syndrome. As a result, it is also obvious that this model also places no limitations on the time of the experiment, except, of course, for those that proceed from the developmental peculiarities of the state being reproduced. /15

In the light of these considerations, the basic objectives in the experiments whose results are reported in this collection were:

– evaluation of the dynamics of the hypodynamic syndrome over the 70-day period of the experiment by clinicophysiological, biochemical, x-ray, psychological, and other study methods;

– determination of the organism's stability to the stress disturbances that are characteristic for the transition from weightlessness to earthbound vital-activity conditions (g-factors, orthostatic disturbances, physical load, etc.);

– testing of methods for running evaluation of the subjects' state, diagnosis of disturbances to the organism that arise during the course of the experiment, and prediction of the subject's possible reactions to the disturbances characteristic of the concluding stage of a flight;

– investigation of the possibility, in principle, of reducing the adverse effects of the weightlessness-simulating conditions on the organism by the use of:

a) various physical-conditioning formulas;

b) certain pharmaceuticals,

c) methods of occlusion conditioning.

The objectives, content, and specific study methods will be set forth in greater detail in the following articles of the collection.

When the study was planned, it was expected that it would contribute to understanding of the biological importance of the gravitational factor to the human organism and to solution of a number of everyday problems posed by practical space exploration. It was assumed at the same time that the material produced by the study would also be helpful from the standpoint of their clinical interpretation, thus contributing to understanding of the pathophysiology of the bedridden regime as such.

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ORGANIZATIONAL AND METHODOLOGICAL PRINCIPLES FOR THE CONDUCT OF PROLONGED HYPODYNAMIA RESEARCHES

P.A. Sorokin, A.M. Genin, M.I. Tishchenko,
P.V. Vasil'yev, R.I. Gismatulin, and I.D. Pestov

ABSTRACT: The influence of prolonged hypodynamia on the human organism was investigated under clinical conditions in five series of experiments in which 16 subjects spent 70 days confined to bed. Series I was the control (pure hypodynamia), consisting of 4 subjects. Series II-V imposed hypodynamia together with various combinations of prophylactic measures on 12 subjects. The most general methodological approaches to study of the effects of hypodynamia and evaluation of the effectiveness of various prophylactic measures are characterized.

The most suitable model of weightlessness available on the earth for long-term experiments is the horizontal position of the subject in bed with restriction of motor activity. Firstly, this modelling method makes it possible to create conditions of hypodynamia (more precisely, hypoergasia) of any desired duration; secondly, it permits application of any test defined by the objectives of the experiment. For a number of reasons, it is advisable to carry out such experimental studies under clinical conditions. Complex changes in the activity of various systems of the organism arise under hypodynamic conditions and require clinical, laboratory, and functional investigation from various aspects. Moreover, constant clinical observation of the subjects is necessary in such experiments, since serious complications may develop during prolonged hypodynamia and require immediate qualified medical attention.

Early in 1966, a special isolated department consisting of two three-bed wards, a room for the attendant medical personnel, and an equipment room was set up to study the adverse effects of /17
prolonged hypodynamia on the human organism and the effectiveness of preventive measures (to the best of our knowledge, this was the first 70-day hypodynamia experiment). Healthy, young (21-23 years of age) male volunteers were used as test subjects. The studies were carried out by specialists in internal medicine, neuropathology, psychiatry, ophthalmology, otolaryngology, aviation and space medicine, biochemistry, epidemiology, nutrition, and other fields.

Five series of experiments were carried out, with participation of five groups of subjects (16 men). Each group of subjects

was studied in three stages: preliminary (background), during hypodynamia, and in the recovery period. After screening and appropriate preparation, orthostatic stability and tolerance of load factors of alternating direction were evaluated for all subjects. After installation in the special department, they then spent 10-12 days undergoing general medical, laboratory, and instrumental examination by all of the specialists participating in the study. During this same period, the studies were supplemented by appropriate functional tests, which were later applied during hypodynamia and during the recovery period. Where the objective of an experiment was pharmaceutical prophylaxis, preliminary studies were made to determine the influence of the drugs on hemodynamics. During the preliminary phase, all subjects were tested to determine basal metabolism and external respiratory function, hemodynamic indicators (by the dye-dilution method), circulatory indicators (by the mechanocardiographic method), minute blood volume (by the acetylene method) (in a number of cases), the phase structure of their cardiac contractions (by the polycardiographic method), cardiac electrical activity, venous pressure, and the state of the blood-coagulating system (by thromboelastography). These studies were accompanied by special neuro- and psychophysiological tests; physical condition and fitness for work were determined and the state of the otorhinolaryngological organs and the visual analyzer were investigated; certain biochemical and bacteriological tests were made; the state of nutrition was studied with determination of the nitrogen and calcium balances. The functional tests used were the orthostatic and hypoxic tests, respiration under excess pressure, and others (the reader is referred to the appropriate articles in this collection for details on the functional tests and the study techniques used). The studies carried out during the background phase were used as a basis for compiling a detailed conception of the functional state of each subject and determination of the indicators whose dynamics would be studied during hypodynamia. At the end of the hypodynamia, the subjects were again given the orthostatic test /18
and subjected to transverse load factors, after which they were returned to their ordinary life patterns. Observations were carried out for three weeks during the recovery phase, and all of the examinations and functional tests described above were repeated. Thus, with rare exceptions, the conditions and methods of the tests were standard in all 5 experimental series.

The object of the series I experiments was to study the changes in the organism's functions during prolonged hypodynamia without taking any measures designed to prevent them. Four subjects participated in the experiment (K-s, K-n, M-s, and Ch-y). Subjects K-s and Ch-y were placed on special cots with which the passive orthostatic test could be carried out at any desired time with a 75° inclination of the torso. To ensure passivity, a crutch-like support with a seat on which the subject sat as he was brought, together with the cot, into the vertical position, was placed on the bunk at these times. The other two subjects

(M-s and K-n) were placed on special suspended pendulum systems (ultralow-frequency ballistocardiographs with a natural oscillation period of about 4 seconds). This posed the problems not only of recording the ballistocardiograms during hypodynamia, but also of investigating the toleration of hypodynamia when the subjects had freedom to move in the horizontal plane, with its effects on the vestibular apparatus. The last subject was placed under similar conditions. Strict confinement to bed was observed. The subjects were forbidden to stand or sit. Movements of the lower extremities were restricted. Throughout the experiment, the subjects did not raise their heads from their pillows and did not turn over onto their stomachs. They were forbidden to indulge in any form of physical exercise. They were allowed only to move their hands and roll onto their sides a few times a day, but again without raising their heads from the pillows. The subjects could read, write, use special reading desks, converse with one another, listen to the radio, and watch television. They were at first fed by the medical personnel, but they learned very quickly to feed themselves without raising their heads from the pillows. Natural functions were attended to with bedpans and urinals.

The daily schedule was adapted to the nature of the studies being carried out. Most of the time-consuming examinations and functional tests and the clinical analyses of blood and urine were carried out at weekly intervals, while the medical examinations were given and the water intakes and diuresis recorded on a daily basis. Certain test procedures to which the subjects had negative emotional reactions, such as the dye-dilution technique and measurement of venous pressure, were carried out no more frequently than twice a week. Blood was taken from a vein for biochemical tests at the same interval. /19

The hemodynamic indicators and their variations during the functional tests, oxygen absorption, and the external respiratory function were studied under basal-metabolism conditions. Studies that did not require observance of basal-metabolism conditions — electrocardiography and polycardiography in the hypoxic test, encephalorheography, electroencephalography, tests of the otorhinolaryngological organs and vision, mental state, and mental and physical fitness for duty — were carried out in the intervals between breakfast and lunch and lunch and dinner. These principles and this schedule were adhered to in all five series of experiments. The test program was invariably rigorous. Despite this, however, the subjects had enough free time and time for political-education programs (watching television, reading, discussions, lectures).

The second and third series of experiments were carried out simultaneously. Part of the objective of these experiments was to study the changes in the organism's systems during 70 days of hypodynamia against a background of prophylactic measures, namely: pharmaceutical cardiovascular and nervous-system stimulants

(series II) and measured physical exertion without leaving the horizontal position (series III). The group of subjects in series II consisted of three men (B-k, B-y, and G-y). The series III group also included three men (K-v, M. M-k, and V. M-k). The series II subjects were placed on stationary orthostatic cots and received the drugs on a cyclical basis (4-day cycle with 9-16 days between cycles) (see the corresponding article). The regime and test methods used for subjects of this series differed in no respect from series I. The series III subjects were placed on suspended systems and performed physical exercises in accordance with special programs (see below) with addition of autogenous-conditioning elements. Otherwise, the subjects observed the same strict bedrest regime as those of series I. This group was observed in the same way as the preceding one.

The fourth and fifth series were also concurrent. The objectives of these experiments included evaluation of the effectiveness of combined physical and occlusion training in preventing hypodynamic disorders. The series IV group (B-v, A-v, K-ya) exercised on a bicycle ergometer while remaining in a horizontal position. The series V group (A-n, L-i, and F-v) exercised on a treadmill. Both groups were given identical occlusion conditioning on a cyclical basis (in weeks 4-5, 7-8, and 9-10). This consisted in application of air cuffs to the upper thirds of the thighs. A pressure of 75-80 mmHg was set up in the cuffs by a special automatic system. This pressure was maintained for a minute. The decompression (pause) also lasted a minute. Since it had not been possible in the previous series of experiments to detect any objective differences in the manifestations of hypodynamic changes between the subjects on suspended and stationary-orthostatic cots, all subjects in series IV and V were placed on identical stationary orthostatic cots. For one thing, this made the investigations easier and, for another, it permitted running the orthostatic tests without transferring the subjects from one cot to another. /20

Since it has been established in the preceding experimental series that the changes in the cardiovascular system during hypodynamia are phasal in nature, with their strongest manifestations during weeks 3-4 and 7-8, the subjects of series IV and V were given orthostatic tests during these periods. Otherwise, the plan and methods of the study were the same as those used in the preceding experiments. Before terminating the hypodynamic regime and testing for tolerance of transverse loads, the subjects of these groups were given pharmaceutical stimulants (Vasil'yev and Lapinskaya, this section).

As we noted earlier, study of the changes in the cardiovascular system in this clinical-physiology experiment was extremely important. At the same time, they would hardly be expected to arise suddenly and abruptly. This substantially increases the importance of dynamic evaluation of the functional indicators for

the cardiovascular system. This raises the accuracy requirements made of these evaluations and requires increased resolution of the test methods used, especially in view of the small number of subjects studied. As we know, each method has its inherent advantages and disadvantages, a definite error, and definite limits of applicability. This is due chiefly to two factors — the quality of the measuring facilities used with the particular method and the influence of the method itself on the object of study. In other words, not only accurate measurement of a given indicator at a given point in time, but also the influence of the subject's unconditioned and conditioned reflex reactions to use of the method itself is of importance for objective evaluation of the indicator. This fact cannot be overlooked in analyzing the results of long-term dynamic observation when there is a possibility of development of conditioned-reflex response to the testing situation.

In view of the need to obtain the largest possible amount of information, to improve its accuracy and reliability, to evaluate minute and gradual changes, to develop and evaluate prognostic criteria and procedures both in the plane of the functional shifts themselves and in the means of their prevention, we made an effort to design the entire hypodynamia study around the general methodological principles set forth below. /21

Redundancy in methods of investigation. The basic hemodynamic indicators were determined by the Stewart-Hamilton dye-dilution method, N.N. Savitskiy's mechanocardiographic method, and in some cases by the Grol'man acetylene method. In addition, the state of the circulatory apparatus was also determined by such general-practice methods as the Korotkov measurement of arterial pressure, palpatory pulse counting, and the like, which should not be overlooked, since they probably are emotionally least disturbing to the subjects. As we had opportunity to learn, this last fact is of no little importance owing to the increasing irritability of the subjects during the experiment. Further, phase analyses of the cardiac contraction were made, for example, both on the basis of data obtained polycardiographically and converted after V.L. Karpman and from kinetocardiographic data. Application of this principle was not limited to the methods for studying the cardiovascular system. Many methods of studying higher nervous activity and evaluating the physical state of the subjects were also backed up. The prime purpose of this redundancy was to broaden the scope of the studies and have them supplement one another. For example, the dye-dilution method make it possible to evaluate the redistribution and mass change of the circulating blood, something that the mechanocardiographic method does not do. At the same time, the mechanocardiographic method enables us to characterize the elastic properties of the vessels and their changes in quiescence and in functional tests. Secondly, it is our opinion that redundancy should provide mutual controls for results obtained by contiguous methods.

Standardization of measurement equipment. This applies first and foremost to the characteristics of the sensors and transducers. A special study enabled us to investigate the characteristics of a number of transducers, which are essentially measuring units (pulse manometers and mechanoelectric transducers), select those that best conformed to the study objectives, and standardize their characteristics for a given experiment. Thus the errors and idiosyncrasies of the measuring equipment became known quantities and could, if necessary, be taken into account in reducing the results.

Standardization of study conditions over the course of the experiment. It is a well-known fact that the cardiovascular and respiratory systems respond alertly to any changes in the environment. Even if it is not accompanied by motor manifestations, an orientation reflex causes changes in cardiac activity, blood-vessel tone, and respiration. By devising standard conditions for the conduct of each type of test (same time, same testing personnel, etc.), we hoped to suppress the vegetative reactions and thereby improve the reliability of the test results with the aid of the differentiations elaborated. At the same time, the experimental conditions did not constitute isolation, since the subjects were in contact with numerous personnel and with one another. On the basis of the above, we counted on the adequacy of the emotional background in conducting our studies. Anticipating slightly, we should nevertheless acknowledge that distinct psychophysiological changes arising during prolonged hypodynamia may make it difficult to evaluate and compare certain data. Toward the end of hypodynamia, all groups of subjects showed increased irritation with a number of test procedures and functional tests that produced unpleasant sensations. In all series, we observed a phenomenon to which we referred as "migration of authority." In it, the liveliest, most cheerful and mobile personality among the subjects of each group acquires "seniority" at the beginning of hypodynamia. At about the middle of hypodynamia, the intragroup hierarchy is readjusted, with this subject turning up at the bottom of the ladder. "Seniority" is transferred to the quietest, best-balanced subject, and he retains it to the end of the experiment. This apparently indicates an effort on the part of the subjects to provide a stereotype in which external irritants are minimized. This need to minimize stimuli may influence the attitudes of the subjects and their reactions to certain types of tests; this, in turn, may affect the test results. /22

Use of certain metrological procedures in evaluating test results. This includes, first of all, evaluation of the reliability of changes that arise in a dynamic series of successive measurements and comparison of these changes in parallel series. As we know, the basic quantity needed for statistical comparison is the root-mean-square (standard) deviation of the aggregate of measurement procedures and instruments that compose the particular study method. Here, of course, we refer to the mediated interaction between the method of measurement and the object of

study. The necessity of determining the standard errors of the methods, which is most often unknown, is dictated by the need to construct confidence intervals for the quantities to be compared. Without doing this, it is impossible to evaluate the statistical significance of changes in the quantities in a sequential series, not to mention quantities obtained on parallel application of different study methods. To develop some idea as to the dimensions /23
of the standard deviations of such methods as mechanocardiography, the dye-dilution method, and the acetylene method of determining blood minute volume, a special metrological study was carried out while they were being applied. We measured the relative changes of the quantities of interest (in particular, the stroke and minute blood volumes) by integral rheography of the body.[1] The figures obtained were taken into account in subsequent statistical processing. As a result, the data were processed by dispersion analysis. In a number of doubtful or questionable cases, we compared populations with pairwise-connected variants.

Active intervention in the course of the experiment. The objectives of the experiment included not only passive observation and recording of hypodynamic disturbances (series I), but also evaluation of prophylactic measures and elaboration of prognostic criteria with a bearing on tolerance of hypodynamia. This was dictated by the need for quick preliminary processing of a number of the data. This need arose primarily in the groups in which physical conditioning was used. The tolerance for the particular form and amount of physical conditioning was evaluated while the experiment was in progress on the basis of electrocardiographic and polycardiographic data. These data were used, in turn, to adjust the amounts of exertion by individual subjects. We attempted to avoid overstressing and the appearance of overconditioning effects in this way. We might also cite here changes made in the conduct of the experiment for certain subjects on the basis of medical indications (see section on clinical studies). These included: terminating the hypodynamic regime for subject K-s (series I) in view of psychoneurological reactions that had appeared, appendectomies on subjects A-v (series IV) and L-i (series V) and the omission of the final load-factor-tolerance tests for subjects V. M-k (series III), K-ya (series IV), and L-i (series V).

The principles set forth above cannot, of course, be regarded as absolute for all test types and stages of the experiments. In making the attempt to adhere to them, we hoped to secure maximum comparability in the data obtained and maximum relevancy for experiments to be conducted in the future. All of this applies primarily to the studies carried out during hypodynamia.

[1]The theory and results of application of this method are beyond the scope of the present clinical-physiology study and are therefore not presented here.

CLINICAL OBSERVATIONS IN PROLONGED HYPODYNAMIA

/24

P.A. Sorokin, V.V. Simonenko, and B.A. Korolev

ABSTRACT: The results of clinical observations on the state of 16 subjects over 70 days of bed rest are reported. The psychological effects of prolonged hypodynamia are analyzed and data on the pathology of the subjects during the experiments are presented.

The information available on the influence of spaceflight conditions on the human organism is comparatively extensive (Gazenko et al., 1964, 1965; Berry, 1967). The functions of the cardiovascular system have been given particularly comprehensive study, but under conditions of simulated weightlessness and in actual spaceflight (Buyanov, 1964, 1967; Kakurin et al., 1966; Deitrick et al., 1948; Graveline et al., 1961; Lamb et al., 1964; Miller et al., 1965, Berry, 1967, and others). This is explained by the special importance of the cardiovascular system. For example, V.V. Parin (1967) regards it as a universal indicator for various disturbances.

New branches of medicine, such as space cardiology (Parin et al., 1965), space gastroenterology (Khazen, 1967; Pfeiffer, 1965) and other trends, have made their appearance in recent years out of the specifics of the conditions and changes of the organism's systems. It must be noted, however, that the influence of hypodynamia on the gastrointestinal tract has been studied for the most part in experiments on restrained animals (mice, rats, monkeys, pigs). In studies of changes affecting the gastrointestinal tract during hypodynamia, the animals were observed to develop ulcers of the stomach, duodenum, and small intestine (Bonfils et al., 1966, Essman et al., 1966; Lambert et al., 1966, and others). In Pfeiffer's opinion (1965), the ulceration is a consequence of stress disturbances.

Ye.V. Maystrakh (1962) argues that restriction of mobility in a spacecraft (suppression of the "freedom instinct," according to I.P. Pavlov) may become a ultrastrong stimulus for man. However, this has not been confirmed during short spaceflights. The cosmonauts have felt neither confined nor lonely — they were absorbed in execution of the flight program and were in close communicati with the earth (Berry, 1967). Nevertheless, the psychophysiological effects of prolonged restriction of mobility on the human organism are unquestionably in evidence.

Apart from its influence on the supporting-and-motor apparatus and the cardiovascular system, limitation of muscular activity results in metabolic disturbances and changes in immunobiological protective reactions. This last circumstance is extremely important. A decrease in the number of bacterial species in the gastrointestinal tracts of isolated animals has been reported (Luckey, 1966). Morphological changes in the organism may result: decrease of lymphoid tissue, blood leucocyte count, and tissue plasma cells. This results in decreased production of antibodies and gamma-globulins in the blood serum. The consequence of this may be increased sensitivity to "nonpathogenic" and conditionally pathogenic bacteria, such as Bact. coli and various cocci. /25

B.A. Chukhlovin and S.A. Burov found that the subjects of our experiments also showed lowered immunity. Cross infection became a more important factor when they were confined together in relative isolation.

Working with rabbits whose rear extremities were immobilized in plaster casts, V.M. Gordiyenko (1962, 1965) observed functional and morphological changes pointing to an inhibition of thyroid function. The mechanism offered for this inhibition by Yu.B. Skebel'skaya (1959) is that during the state of stress, the hypophysis secretes, together with ACTH, some substance that suppresses the function of the thyroid gland. A study of suprarenal function in 11 pilots during 10 days of confinement to bed produced no data confirming the influence of the horizontal position and restriction of motor activity on suprarenal hormone secretion (Katz, 1964).

Observations have indicated that prolonged limitation of motor activity results in atrophy of muscle tissue and demineralization of the bones (Deitrick, 1948; Newman, 1963, and others).

The tendency to bone fractures increases when osteoporosis develops. At the same time, increased excretion of calcium and other mineral salts with the urine may contribute to the formation of stones in the urinary tracts and to the development of a sclerotic process in the kidneys (Cockett, et al., 1962; and others).

The data given above indicate that the hypodynamic effect is accompanied in all of the procedures used to simulate weightlessness by substantial changes in the organism's functions. Prolonged immobilization may give rise to various complications, and the development of acute pathological states is not excluded.

The present article examines data from clinical observations made in various series of experiments on 16 healthy males ranging in age from 21 to 23 years, who spent 70 days confined to bed.

During the first few days of hypodynamia, the subjects remarked only on the awkwardness of taking food and performing

natural functions (use of the urinal and bedpan). On the second or third day of the bed rest regime, some of the subjects expressed the desire to stand up, sit up, or walk around. Signs of disturbed sleep began to make their appearance: the subjects found it difficult to go to sleep at night, and many of them slept fitfully, with frequent awakenings and nightmares. The sleep disturbances were more pronounced durnng the first and second weeks of the hypodynamia, but they persisted in one degree or another over the entire period of confinement to bed. Some of the subjects complained almost constantly of headaches, heaviness in the head, and dizziness (A-n, F-v, G-y, K-ya, L-i, K-s, and M-s). The mood of the subjects varied. Instability of mood over the course of a day and its dependence on the mood of the other subjects were phenomena that appeared at the end of the second week of hypodynamia. Some subjects showed signs of increased irritability and neurotic reactions (K-s, M-s, V. M-k, B-v, L-i, Ch-y, K-v, M.M-k, K-ya). They took expression in a negative attitude to certain tests, the doctors, and the attendant personnel. This required great tact on the part of the doctors and nurses, and a cautious and alert attitude toward the subjects. Subjects B-y, B-k and G-y were particularly nervous during the phase in which the nervous and cardiovascular systems were pharmacologically stimulated. /26

A certain adaptation to the new conditions of existence was observed from the third week of hypodynamia. Certain subjects no longer had the desire to move (A-n, third week). Statements such as "I'm fed up with hypodynamia" were still being made during the fourth week of confinement to bed (V.M-k). Nevertheless, all subjects remained at all times in the mood to complete the task ahead of them.

It should be noted that all subjects eagerly awaited the end of the experiment. Statement (and diary notations) to this effect became more and more frequent after the 7th-8th weeks of hypodynamia ("Expectation" neurosis). Thus, subject A-v wrote in his introspection diary on May 27, 1967 (7th week of hypodynamia) that "Mood changes like the weather in Leningrad. I am no less bored with this diary than with hypodynamia. And I usually feel better when there is no one here and no one is laughing. The northern lights disturbed my sleep." Before the experiment, this subject had been particularly well-balanced and even-tempered.

During the first and second weeks in bed, almost all subjects complained of pains around the waist and weakness. The desire to move, stand up, and walk around that had been in evidence during the first week had been supplanted by the end of the 3rd week by apathy and lethargy. Muscles lost their tone. Some of the subjects reported pains in their joints (K-v, A-n). After the passive orthostatic test, subject A-v (8th week of hypodynamia) reported that he was as tired as though he had been engaged in heavy physical labor. After hypodynamia (during the recovery phase), all subjects had pains in the joints of the lower

extremities and muscle pains. The subjects walked unsteadily and diffidently, and walking was accompanied by considerable pain in the joints; in walking, they hobbled as though they were attempting to favor both legs. These phenomena persisted even into the third and fourth weeks after the return to the active life pattern.

In the initial phase, the subjects had no complaints regarding their cardiovascular systems. Nor did clinical electrocardiographic examination detect any pathological changes. Only in subject A-v was a functional systolic sound (confirmed by photocardiographic examination) heard over the apex of the heart. During hypodynamia, subjects K-v (10th week) and L-i (2nd week) complained of pains in the region of the heart. Subject L-i (8th to 10th week) reported palpitations. Subject K-s had nosebleeds, and V. M-k had bleeding gums. /27

All subjects showed a certain pallor of the skin and visible mucous membranes when examined during hypodynamia.

Phase changes were observed in the pulse and arterial pressure as measured with the stethoscope. During the first two weeks of confinement to bed, there was pronounced bradycardia and a drop in arterial pressure. Later, and especially toward the end of hypodynamia, the pulse rate increased and the arterial pressure rose slightly over the values for the initial period. These phase changes were most pronounced in subjects of the first (control) and second series of experiments (Figs. 1 and 2). In the other series, in which the subjects did physical exercises or combined these with occlusion conditioning, the hypodynamic phase shifts were indistinct. Wide variations in pulse rate and arterial pressure level were observed over the entire period of confinement to bed (Fig. 3).

According to percussion, the boundaries of the heart did not change in any of the subjects during hypodynamia. A functional systolic sound was heard in some cases over the apex of the heart. Subject L-i complained constantly of arrhythmia (left-ventricular extrasystole). As the time of hypokinesia increased, the cuff test produced punctiform (usually abundant) extravasations in the skin of the lower extremities (subjects B-v, L-i, Ch-y), i.e., they showed a positive Rumpel-Leede-Konchalovskiy symptom.

No pathological changes in the respiratory organs were observed during clinical examinations in the initial phase. During hypodynamia, catarrhal states of the upper respiratory tract were frequently observed: rhinitis, nasopharyngitis, and bronchitis (see table). This is apparently to be explained by activation of conditionally pathological flora in the respiratory passages during hypokinesis and a decline in the organism's protective capabilities. Catarrh of the upper respiratory passages was noted in subjects K-n (3rd week), M.M-k (4th week), B-v (1st, 3rd and 8th

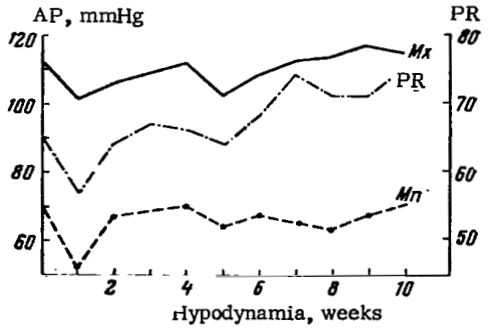

Figure 1. Variation of Pulse and Arterial Pressure (Korotkov Method) in Subjects of Experimental Series I (Averaged data). Mx is the maximum arterial pressure; Mn is the minimum arterial pressure; PR is the pulse rate.

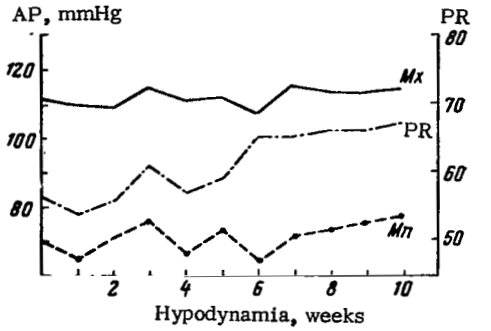

Figure 2. Variation of Pulse and Arterial Pressure (Korotkov Method) in Subjects of Experimental Series II (Averaged data). Mx is the maximum arterial pressure; Mn is the minimum arterial pressure; PR is the pulse rate.

/28

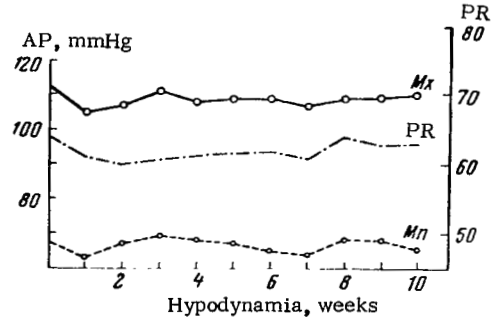

Figure 3. Variation of Pulse and Arterial Pressure (Korotkov Method) in Subjects of Experimental Series IV (Averaged data). Mx is the maximum arterial pressure; Mn is the minimum arterial pressure; PR is the pulse rate.

weeks), K-ya (3rd week), and F-v (2nd, 5th, and 8th weeks). In the case of F-v, a vasomotor rhinitis contributed to the catarrh. Involvement of the bronchial mucosa in the inflammatory process was established in subjects M. M-k (4th week), B-v (3rd week), and F-v (8th week). This was manifested clinically in complaints of coughing and dry rattling sounds in the lungs. These disorders responded to treatment (gargling, peroral administration of aspirin and sulfanilamides). At the 6th-7th weeks, subject K-ya developed bilateral otitis media, which responded poorly to treatment with sulfanilamides and antibiotics.

/29

The preliminary study of the subjects' digestive organs prior to the experiment had consisted in interviews, examination, palpation of the abdominal organs, and study of fecal matter (coprocytogram). In the case of subject B-y, the duodenal contents were studied and Lamblia were detected. For the remaining subjects, clinical examination carried this far did not indicate any

TABLE 1. ILLNESSES OF SUBJECTS DURING HYPODYNAMIA

Exptl. series	Subject	Initial period			Period of hypodynamia							Recovery period	
		Days of observation period											
		1–10	11–20	21–30	1–10	11–20	21–30	31–40	41–50	51–60	61–70	1–10	11–20
I	K-s M-s Ch-y K-i				Nosebleed		Vestibular disturbance, neurosis URP catarrh	Dropped from experiment					
II	B-k B-y G-y	Lambila carrier			Cholecystitis exacerbated Nettle Rash	Streptodermia			URP catarrh			Vulgar urethritis	
III	K-v V.M-k M.M-k		URP catarrh URP catarrh		Sty Vulgar urethritis	Gingivitis	URP catarrh	Subfebrility					
IV	B-v A-v K-ya			Pytiriasis versicoloe		URP catarrh	Bronchitis URP catarrh	Acute phlegmonous appendicitis Sinistral, then bilateral otitis	Rhinitis	Caries Yeast fungi in urine			Yeast fungi in urine
V	L-i A-n F-v	Submaxillary furunculosis	URP catarrh	Caries, exacerbation of chronic pulpitis		Head-cold Vasomotor rhinitis		Albumen and fresh erythrocytes in urine	Bronchitis	Arrhythmia Sty Yeast fungi in urine, subacute pharyn.	Acute phlegmonous appendicitis		Mucus in urine

disturbances or illnesses affecting the gastrointestinal tract. This was confirmed by the absence of complaints, good general physical condition, and normal state of nutrition of the subjects. Clinical observations made during hypodynamia fully justify the statement that the largest number of complaints involved the gastrointestinal tract. This applies primarily to loss of appetite. Before hypodynamia, the subjects had good appetites and usually ate everything placed before them. Complaints of poor appetite and the bad taste of the food appear during the first few days of hypodynamia. The subjects began to leave food on their plates. Measures were taken to improve the taste qualities of the food and increase the assortment of dishes, but they did not succeed in fully restoring lost appetite. Subjects K-v, M. M-k, and A-n complained constantly of poor appetite. In addition, some subjects reported a bad taste in the mouth. Most of their tongues were white-coated (K-n, M.M-k, B-v, and L-i). The subjects had bad breath in spite of the care given the oral cavity - brushing the teeth in the morning, use of mouthwash). Subject L-i reported heartburn. /31

As we noted above, the subjects reported that it was awkward to perform natural functions while lying down (to use the urinal and bedpan) during the first few days of hypodynamia. To some degree, this resulted in retention of the stool during the first few days. Later, performance of these functions in the supine position caused the subjects no particular inconvenience. The stool was usually passed every day or two and at the same time, but with considerable straining on the part of the subjects, owing to the dense consistency. Subjects Ch-y, K-n, K-v, and L-ya were persistently constipated (stool every 2-3 days), and this was accompanied by abdominal pains, headache, and deterioration of mood. Laxatives were prescribed for these subjects. As a result of constipation, subjects K-n and Ch-y developed bleeding lacerations of the rectum.

Palpation of the abdominal organs indicated a spastic state of the large intestine and a certain sensitivity in the epigastric region and the right hypochondrium. No enlargement of the liver was detected here.

Thus, the clinical observations indicate functional disturbances of the gastrointestinal tract. The prime manifestations of this were the loss of appetite and constipation.

The subjects usually showed loss of body weight (by 2-7 kg) during hypodynamia. Only in two subjects of series III and IV did body weight remain practically constant (K-v, A-v). The loss of weight was due in part to the fact that the subjects did not eat well.

Of 6 subjects in experiments IV-V, 2 developed acute appendicitis: A-v in the 5th week and L-ya in the 8th week of hypodynamia.

. re, special note should be taken of the vagueness of the clinic[illegible] picture. With destruction of the appendix present in both cas[illegible] (phlegmonous appendicitis), the clinical symptomatics were scanty: moderate pain in the right iliac region, no temperature reaction or symptoms of peritonitis. However, leucocytosis was manifest in both cases (15 100 for A-v and 10 750 for L-ya). Postoperative recovery was smooth, healing by primary intention, and the sutures were removed after 8-10 days. However, L-ya's pains in the region of the incision persisted for three weeks after removal of the sutures. This indicates a certain decline in tissue regeneration in the region of the incision. Two factors appeared to be operating in the etiology of the acute appendicitis: interference with defecation (L-ya suffered from constipation) and activation of conditionally pathogenic flora of the large intestine under the influence of hypodynamia. /32

No kidney disorders were detected during the initial period.

During the 2nd week of hypodynamia, subject V.M-k developed a vulgar urethritis, whose course was sluggish and which required special treatment under the supervision of a urologist. It was established from the anamnesis that he had previously suffered from vulgar urethritis, and that it had apparently been exacerbated with the decline in his immunobiological resistance. Subject G-y also had an episode of vulgar urethritis during the recovery period (a white nonhemolytic staphylococcus was isolated in a urine culture).

Along with the illnesses noted above, nettle rash (G-y) and frequent pustulous eruptions of the skin (furuncles, streptodermia, sties) were observed.

CONCLUSION

First of all, the clinical observations established that prolonged hypodynamia has a definite psychological effect on the subjects. As we know, freedom to engage in physical activity is a natural need of a healthy human. Its suppression during confinement to bed gives rise to corresponding associations and a desire for exercise that steadily increases in intensity. This would apparently explain the appearance of a kind of "expectation neurosis" in some of the subjects toward the end of the experiments. However, willpower and the desire to complete the assigned task prevented the development of neurotic states in most of the subjects. This is indicated by the fact that 15 of the 16 subjects stayed on to finish the job. Only one subject (K-s) was dropped from the experiment because of pronounced psychoneurotic reactions that had developed.

The human suffers unfavorable effects from reduced muscular activity, which is a physiological result of homeostasis and the functions of the cardiovascular, digestive, and other systems of

the organism (Korobkov, 1961; Mogendovich, 1961, and others). Our clinical observations indicate a pronounced functional disturbance of the gastrointestinal tract. Unfortunately, we cannot state the nature of these changes with confidence, since we were unable to carry out specific investigations in this direction.

The decline in the organism's immunobiological resistance during hypodynamia merits serious attention. Observations made on the subjects showed increased susceptibility to conditionally pathogenic flora. This is indicated by exacerbation of latent /33 foci of infection and the appearance of pyodermias and inflammatory disorders of the upper respiratory passages and otorhinolaryngological organs. There is reason to assume that extremely threatening complications may also be expected to arise in prolonged hypodynamia. This is indicated by the two cases of phlegmonous appendicitis. Vagueness of the clinical picture must be regarded as a peculiarity of the destructive (phlegmonous) appendicitides.

All of the disturbances observed in the subjects can be classified conditionally as postural discomfort effects, temporary functional disturbances, and illnesses. In the first two cases, either no particular intervention by the physician was required or it was limited to advice and the prescription of certain symptomatic medications (analgesics for headache and joint pains, laxatives for constipation, etc.).

The appearance of such disorders as pyodermias, catarrh of the upper respiratory passages, otitis, and urethritis urgently required specific treatment. As a rule, the course of the disorder was sluggish. Appropriate treatment was required after determining the nature of the agent and its sensitivity to antibiotics. Such therapy was usually successful. However, K-ya's case of acute otitis did not respond well to sulfanilimides and antibiotics. Improvement began when the patient was allowed to resume normal motor activity. Finally, special attention must be given to acute appendicitis, a common affliction with potentially grave complications. It is not difficult to diagnose, but in the absence of medical observation, it may not be recognized in time owing to the vagueness of the clinical picture. Timely appendectomies give good results, as is indicated by the favorable outcome of surgical intervention in our subjects.

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CHANGES IN ELECTROCARDIOGRAM AND STATISTICAL STRUCTURE OF CARDIAC RHYTHM IN THE COURSE OF CONFINEMENT TO BED

A.D. Voskresenskiy, B.A. Korolev,
and M.D. Ventsel'

ABSTRACT: Analysis of EKG recorded during a 70-day confinement to bed showed position changes, relative inhibition of conduction, decreased amplitude of the R and T deflections, a change in the relationship between the T from various leads, a periodic displacement of the S-T segment, and changes in the repolarization process for all of the subjects. These shifts appeared later and were less consistent in subjects who performed a set of physical exercises. Correlation functions calculated for series of 200-300 successive values of the R-R interval revealed a picture of respiratory-arrhythmia decay and the appearance of undulating variations of the rhythm that were not related to respiration. The R-R correlation functions showed little change from their original form in the individuals who performed physical exercises.

Despite the numerous papers devoted to study of the influence of prolonged confinement to bed on the cardiovascular system (Kakurin, Katkovskiy, 1966; Genin and Sorokin, the present collection; Lamb, 1966), data on EKG changes are limited to reports of quickened cardiac rhythm and lowered amplitude of the R and T deflections. The present report sets forth the results of a systematic study of the EKG records obtained during quiescence under basal-metabolism conditions from 16 subjects during various phases of the confinement to bed. Special EKG were also recorded to investigate the rhythm of the cardiac contractions by the method of statistics and correlation analysis. A "Dnepr" electronic digital computer was used for mathematical processing of the data by the method described earlier (Voskresenskiy, Ventsel', 1965). /35

RESULTS OF INVESTIGATION

All of the subjects showed a distinct tendency to quickening of the cardiac rhythm. According to data obtained under basal-metabolism conditions, a reliable increase in pulse frequency was observed in the various experimental series as early as weeks 1-5,

and the maximum increase above the initial level at 5-10 weeks into the bedrest experiment. The largest values of the difference between the background and experimental values of pulse frequency reached 23.3 beats/min (series III, week 5) and 21.0 beats/min (series I, week 10).

According to the records taken for mathematical analysis of the cardiac rhythm, the average pulse-frequency values differed substantially between the groups of subjects who did and did not engage in physical conditioning as early as weeks 1-3, but then tended to equalize and remained very closely similar throughout the rest of the confinement to bed.

Analysis of the EKG for all subjects showed position changes, relative inhibition of intraatrial, atrioventricular, and intraventricular conduction and conduction through the right branch of the bundle of His. The amplitude of the $P_{2,3,aVF}$ deflections increased periodically, and the shape of the P_{V_1} deflection changed. The amplitudes of the R and T deflections decreased; sometimes the $T_{3,aVF}$ deflection flattened out and became negative. The height of the T_{V_6} deflection decreased, while that of T_{V_1} increased. The $T_{V_1} > T_{V_6}$ syndrome became positive. The S-T segment changed position periodically, shifting below the isoline in the aVF leads and the standard III lead, or above the isoline in the aVL and V_{1-4} leads (Figs. 1 and 2). These changes were especially pronounced during the first two weeks of the recovery period.

The repolarization process changed in all subjects, especially those of series III-V. The duration of the aT-aU and S-aU segments increased by 0.04-0.06 second above the "ideal" values.

A decrease in the magnitude of the T-vector and the ventricular gradient was observed on vector analysis. The magnitude of the QRS vector decreased in series III-V and increased in series I and II. The increase of $Q\hat{R}S$ may result from broadening of the QRS complex, i.e., the inhibition of intraventricular conduction. The most pronounced changes in the repolarization process were noted in series II-V, and the decrease in the vector magnitudes was largest in experimental series III and V. /36

The electrocardiogram changes took the same direction in all series of experiments. In the subjects of series I and II, however, these changes appeared earlier, during weeks 1-2, while in series III-V, they appeared at weeks 4-5 of the experiment and were less consistent. Breathing of a gas mixture containing 90% of nitrogen and 10% of oxygen stimulated the manifestation of the EKG shifts described above. In some subjects, they appeared 2-3 weeks earlier in response to hypoxia than they did on EKG taken under ordinary rest conditions.

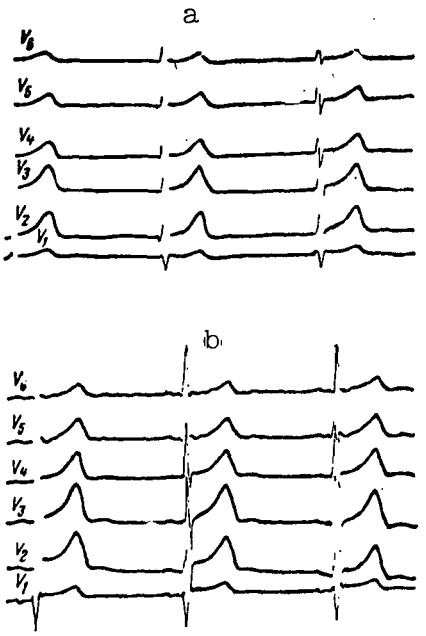

Figure 1. Variations of EKG in Subject A-v. a) During Initial Period; b) At 9th Week of Confinement to Bed. The rsr' Form Appeared in the V_1 Lead; the S-$T_{V_{1,2}}$ Interval Rose Above the Isoline, $T_{V_1} = T_{V_6}$; the Amplitude of the $U_{V_{1-6}}$ Deflections Increased.

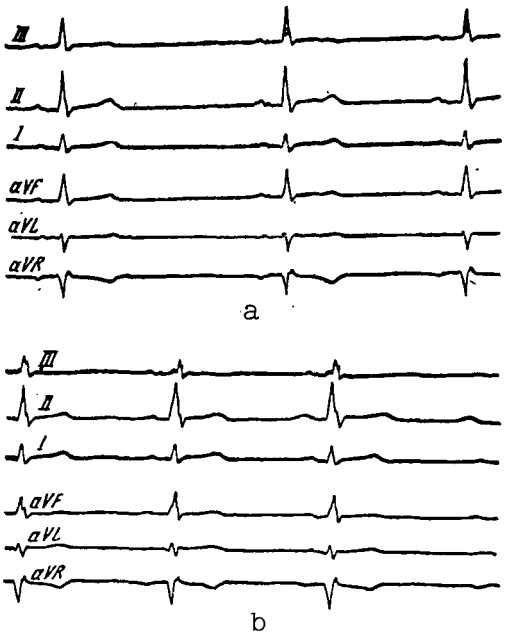

Figure 2. EKG Changes in Subject B-y. a) During Initial Period; b) at 7th Week of Confinement to Bed. The Increase in the Amplitude of the R Deflections is Evident. The $R_{3,aVL,aVF}$ Deflections are Split. The Width of the P Deflection Increased to 0.14 sec, and That of the QRS Complex to 0.12 sec. The S-$T_{1,2,aVL}$ Interval Rose Above the Isoline, and the T_3 Deflection Became Negative. The Amplitude of the $U_{1,2,aVR,aVF}$ Deflections Increased.

On examination of the statistical cardiac-rhythm characteristics, our attention was drawn to a decrease in the coefficient of variation of the R-R interval. In the series I and II subjects, the lowest values of this indicator were obtained during the last week of confinement to bed, when pulse frequency reached its maximum values. Among the subjects who performed sets of physical exercises, the lowest coefficients of variation of R-R corresponded to the second week of bed rest, and the final values averaged higher than in series I-II. The asymmetry coefficient of the R-R distribution showed a tendency among series I-II subjects to shift toward positive values, while in series III-V it remained near its original value. However, owing to the sharp individual variations in these indicators, the differences noted in their dynamics were not statistically significant.

Analysis of the correlation functions for series of successive values of the R-R interval made it possible to discern substantial changes in the periodic structure of the cardiac rhythm among subjects of experimental series I and II.

During the background study and during the first few days of confinement to bed, almost all of the autocorrelation-function curves showed distinct waves reflecting respiratory arrhythmia. For the most part, the amplitudes of these waves were constant or varied periodically about a stable average level, indicating a high degree of order in the respiratory fluctuations of cardiac rhythm (Fig. 3). So-called "slow waves," which reflect variations of the rhythm with a period of approximately 60 to 120 cardiac cycles, were superimposed on the respiratory periodicity in some of the subjects. These slow periodic oscillations were scarcely noticeable in some cases, but in others they were very clear, and they ranged up to considerable amplitudes on the correlation function.

/38

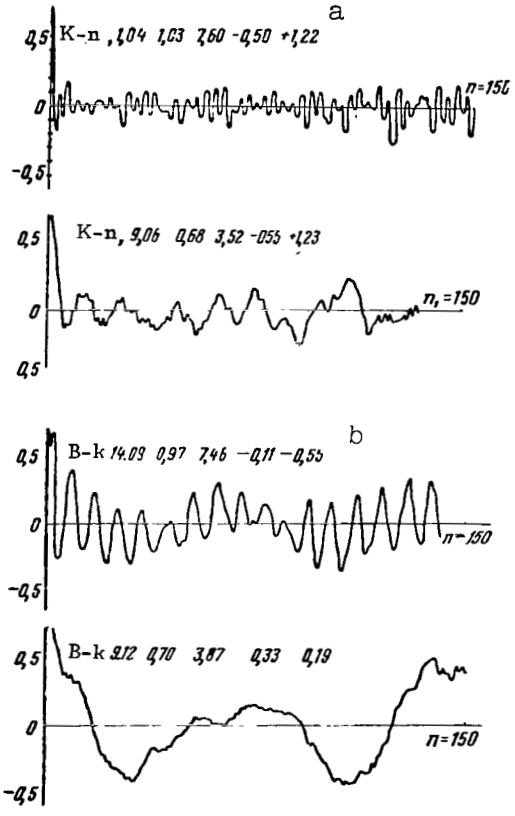

Figure 3. Autocorrelation Function of EKG R-R Intervals in Subjects (A) K-n and (B) B-k from Background Examination (upper curves) and Before Termination of Confinement to Bed (lower curves). The Numbers of the Successive Cardiac Cycles (Numbers of Shifts) are Plotted as Abscissas, and the Correlation-Coefficient Values as Ordinates.

/39

The autocorrelation curves of series I subjects were characterized by decay of the respiratory periodicity over the course of the confinement to bed. Respiratory oscillations smoothed out or merged, forming waves without a stable period or repeating form. These waves did not usually exceed 0.2 in amplitude, and their period covered no more than 30 cardiac cycles. In some cases, it was altogether impossible to find a periodicity on these curves that would reflect respiratory arrhythmia (Fig. 3a). This pattern of correlation-function changes was noted for subject K-s as early as the 10th day of the experiment. In two other subjects, the disturbance to the periodic structure of cardiac rhythm was brought out

after the first month of confinement to bed, and in another subject it appeared immediately before termination of the experiment.

The results from reduction of the data obtained from the series III subjects also indicated sharp changes in the correlation functions. In two cases, the respiratory periodicity disappeared altogether. The waves on the autocorrelation curves had periods covering approximately 12-15 or 60-80 cardiac cycles. In contrast to the "slow waves" observed during the background study, these fluctuations of the autocorrelation curve had very high amplitudes. Their total amplitudes reached 0.40-0.45 (Fig. 3b).

The correlation functions of the series III, IV, and V subjects had almost the same form at the end of confinement to bed as they had had during the background examinations.

Signs of reduced ordering of the respiratory periodicity could be discerned in some cases: smoothing and merging of neighboring oscillations and the appearance of waves with a regular configuration. However, these changes were substantially less pronounced than among the series I and II subjects.

DISCUSSION

The combination of inhibited conduction and changes in the repolarization process and in the amplitude and shape of certain EKG elements might suggest the presence of some sort of diffuse disturbance to metabolic processes in the myocardium. The most probable cause of metabolic changes might be looked for in the shifts of water-salt metabolism that always accompany prolonged confinement to bed (Kakurin, Biryukov, 1966). The work of V.S. Sal'manovich (1962, 1967) indicated that changes in the K and Na ion concentrations are reflected most strongly in the conduction system of the heart, and also established the ionic nature of the shift in the S-T segment in myocardial ischemia. However, the deviations of the K and Na ion concentrations found in the blood serum of the subjects (Ivanov, et al., this collection) are far from the critical values capable of causing EKG changes (Brikker, 1966). Further, the pattern of the EKG changes does not, on the whole, fit any of the known forms of pathology associated with disturbance of ionic balance (Dekhtyar', 1966; Brikker, 1966). As for disturbances to calcium metabolism, their ability to cause serious functional disturbances of the cardiovascular system during prolonged restriction of mobility has been questioned (Kakurin, Biryukov, 1966; Miller, 1965). Two-month experiments on 6 subjects who were strictly confined to bed indicated that even highly strenuous physical exercises have no influence on the changes in water-salt metabolism that result from redistribution of the blood (Biryukov et al., 1967). If we proceed on the assumption that these shifts in water-salt metabolism can seriously impair the contractile property of the myocardium, it becomes difficult to explain how the subjects retain the ability to handle

/40

heavy physical loads throughout the experiment, and even a load-factor tolerance near the initial level (Kotovskaya et al., this collection).

The hypothesis has been advanced that a decrease in the work demand made of the myocardium may be accompanied by a decrease in coronary circulation and the capacity of the coronary lumen, as well as by an accumulation of catechinamine products in the myocardium, which changes the contractile characteristics of the muscle fibers and increases the tendency to arrhythmia (Lamb, 1966).

To interpret the results of the present experiments, it is obviously necessary to evaluate the role played by intracardiac factors. However, it must be remembered that a substantial number of the electrocardiographic shifts can be explained in terms of the complex of extracardiac factors.

A sojourn under conditions of limited mobility is accompanied by a decrease in the level of parasympathetic actions on the heart and quickening of the cardiac rhythm. This process takes place against a background of unique neurological shifts (Panov, Lobzin, this collection), whose manifestation on the part of the cardiovascular system can apparently be regarded as a neurocirculatory dystonia that facilitates adrenergic reactions. The latter may be accompanied by the appearance of a number of EKG changes of various types. It is known that individuals with healthy hearts but unstable autonomic nervous systems often produce EKG with missing S-T segments and flat or negative T deflections (Dekhtyar', 1966).

It must be remembered at the same time that the subjects of the present experiments were young people who had received good physical conditioning and athletic training. Inadequate tachycardic reactions of the "athlete's" heart in the absence of volume and resistance loads or the conditions for hyperfunction probably cause at least part of the EKG changes observed among the subjects in the present study. The chronocardiograms of sportsmen relaxing in the absence of high conditioning loads may acquire features of the phase syndrome of hypodynamia (Karpman, 1965). In the absence of loads, the hypodynamia syndrome is compounded by lengthening of /41
the expulsion period and the disappearance of the electromechanical difference (Butkov, 1966). It is possible that similar relationships form the basis for certain electro- and chronocardiographic differences between the subject groups.

As for the results of mathematical analysis of the cardiac rhythm, only the first attempts have thus far been made to evaluate the diagnostic and physiological importance of the various indicators (Zhemaytite, 1965; Sarsaniya, 1966; Parin et al., 1967). Analysis of literature data tends to indicate that the decay of respiratory arrhythmia on the autocorrelation curves of the R-R interval is due to disturbance of the complex reflex connections

that determine the inhibiting effect of the vagus nerve on the vasomotor centers (Okada, Fox, 1967). It must be stressed that the correlation curves for the R-R interval were most informative for differentiation between subjects who did and did not do physical exercises during the experiments.

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HEMODYNAMIC CHANGES DURING PROLONGED HYPOKINESIA ACCORDING TO MECHANOCARDIOGRAPHIC DATA

/42

V.V. Simonenko

ABSTRACT: A dominant influence of the sympathetic innervation on the cardiovascular system is observed during prolonged hypokinesia. Prolonged hypokinesia changes the reaction of man to cold, as manifest in the phasing of the reactions, lower strength of the response reaction, and lowering of the tonicity coefficient of the blood vessels. The cuff test can serve as a tentative indicator of the ability of the cardiovascular system to react during hypokinesia to compensate exclusion of a certain amount of blood from circulation. Physical conditioning mitigates the deconditioning effect of hypokinesia on the cardiovascular system to some degree, but does not eliminate it completely.

Even after relatively short periods of hypokinesia (5-30 days), various authors (Deitrick et al., 1948; Myasnikov et al., 1963; Buyanov, 1964, 1967; Kakurin et al., 1966; Ioffe et al., 1966; Sorokin et al., 1967; Miller, 1965) have reported substantial functional disturbances of the cardiovascular system that may be due to a number of changes in the supporting and motor apparatus and disturbances to water-salt metabolism and neurohumoral regulation of the cardiovascular system (Vanyushina, 1963; Gauer et al., 1963; Goodal et al., 1964; Miller, 1965). We studied the state of hemodynamics and vascular tone in 16 healthy males ranging in age from 21 to 23 years, who spent 70 days strictly confined to bed.

The basic hemodynamic indicators were determined on the mechanocardiograph, using N.N. Savitskiy's tachooscillographic and sphygmographic method. The hemodynamic indicators were determined under basal-metabolism conditions twice during the initial period (before the experiment) and daily during hypokinesia and the recovery period (up to 3 weeks). The functional tests used were the Hines-Brown cold pressor test (Hines, Brown, 1933) and the Schwalm cuff test (Schwalm, 1953).

The basic hemodynamic indicators were processed by the method of variational statistics. The results of investigation from the background period were compared with the data obtained during hypokinesia, and the hemodynamic indicators of a control series

were also compared with the other series.

Study of hemodynamic changes in the functional tests made it possible to establish that the largest changes intervene at the 90th second of exposure to cold in the cold pressor test and at the 20th minute of compression in the cuff test.

EXPERIMENTAL RESULTS

The results of the experiments indicated the following average values of arterial pressure for the initial period: minimum 63-68.8; average 81.5-86.8; true systolic (lateral) 98-103.5; final systolic 115-122.7 mmHg, i.e., they were normal for individuals in this age range (the figures given are the ranges of the averages over experimental series I-V).

The arterial pressure showed no substantial change among subjects of series I during hypokinesia. /43

Series II subjects showed a rise in the minimum pressure by 10-11 and on the average by 12-14 mmHg at the 4th-9th weeks of confinement to bed ($0.001 < P < 0.01$). During this period, the average arterial pressure was found to be 10-17 mmHg higher than in the control (series I).

A reliable 7-13-mmHg rise in pulse pressure was observed in series II, IV, and V subjects from the 4th through the 7th weeks of confinement to bed ($0.01 < P < 0.05$). There was no substantial change in pulse pressure in the other experimental series.

Although the frequency of cardiac contractions rose during hypokinesia in subjects of all series, these changes were not quantitatively uniform. In experimental series I, II, and IV, the pulse rate showed a reliable increase at the 7th week by an average of 14 beats per minute, and at weeks 8-9 by 15-19 beats per minute. In series III and V, the increase in pulse frequency was less distinct (8-13 beats/min) and was found to be statistically unreliable. After termination of hypokinesia, a slightly higher cardiac frequency persisted in most of the subjects. It had not reached its initial value even two weeks after the return to the normal life pattern.

In subjects of experimental series I, II, and IV, stroke volume varied irregularly during hypodynamia, with a tendency to show a slight increase from the 2nd through the 7th week of confinement to bed. A statistically reliable stroke-volume increase was noted only in subjects who exercised systematically on a treadmill (series III and V).

The increase in circulation minute volume was found to be substantial (1.5-2.2 liters) and reliable ($0.01 < P < 0.05$) in series

II, IV, and V at the 4th, 5th, 7th, and 9th weeks of confinement to bed.

In the subjects of these series, minute circulation volume increased basically as a result of increased cardiac frequencies, and, in series V, also because of an increase in the systolic ejection.

Peripheral resistance decreased during hypokinesia. The contractile power of the left ventricle averaged 2.74-3.24 W over the various series before the experiment. Beginning at the 4th week of confinement to bed, the contractile power of the left ventricle rose reliably ($0.01 < P < 0.05$) by 1.0-1.5 W in the subjects of experimental series II, IV, and V. The heart's expenditure of energy to transport one liter of blood had averaged 10.67 -11.42 W before the experiment. During hypokinesia, it rose reliably by 1.5-2.0 W among series II subjects, but did not change substantially in the other series.

The tone of the aorta and muscle-type vessels of the upper extremities, which was determined from the rate of propagation of the pulse wave on the corresponding vessels, showed fluctuations. Thus, the rate of pulse-wave propagation along the aorta (Ve) had averaged 657 cm/sec before the experiment, and that along muscle type vessels in the upper extremities had been 752 cm/sec. The observed changes in Ve and Vm during hypokinesia were unreliable. The coefficient Ve/Vm underwent no substantial changes under basal-metabolism conditions. /44

Among the series IV and V subjects (the determination was not made in the other series), the rate of pulse-wave propagation along muscle-type vessels in the lower extremities had averaged 795 sec/cm [sic] before the experiment. During hypokinesia, there were wide variations of vascular tone in the lower extremities (Vm varied from 465 to 1214 cm/sec).

The capacity of vessels in the lower extremities for vasoconstrictor reactions in the vertical position was preserved after hypokinesia. This is indicated by an increase in the pulse-wave propagation velocity in the vertical position by a factor of 2-2.5 (from 584-738 to 1558-1600 cm/sec).

To evaluate the unconditioned-reflex reaction of the vessels during hypokinesia, we used the Hines-Brown cold pressor test. In the opinion of the authors, the cold pressor test is a standard pressor test. In healthy persons, exposure of the hand to cold (water at +4°C) for 60 min raises the minimum arterial pressure by +15 mmHg and the maximum by +20 mmHg. Individuals with higher arterial pressure increases are classified as hyperreactive. Among individuals with normal arterial pressure, the percentage of hyperreactors, as reported by various authors, has ranged from 6 (Arganovich et al., 1950) to 56.7 (Russek et al., 1945).

Extensive use of this test for diagnosis of prehypertonic conditions has somewhat shaken Hines and Brown's conception of the cold test as a standard. However, all investigators who subsequently studied vascular reactions to cold are unanimous in their conclusion that the cold test gives a pressor effect whose magnitude is individual.

Detection of peculiarities in the response to cold during prolonged hypokinesia was of particular interest from our standpoint. According to L.I. Kakurin et al. (1966), who studied the response to cold during 20-day hypokinesia in 4 young males, the cold pressor test administered in hypokinesia gives rise to a vascular spasm (maximum arterial pressure rose from 110 to 190 mmHg on exposure to cold). It should be noted that the authors used a 3-minute cold test with the cold applied to the hand and forearm.

The results that we obtained from cold tests during the initial period (before hypokinesia) made it possible to class 4 subjects out of 16 (25%) as hyperreactors on the basis of their response. Thus, this reaction was observed in K-s among series I subjects, in K-v and M.M-k in series III, and in B-v of series IV. Subjects B-k and B-y (series II) showed a somewhat exaggerated response of maximum arterial pressure to cold (more than +20 mmHg). All series V subjects reacted normally. /45

During the 70-day period of hypokinesia, 8 of the 16 subjects showed an enhanced reaction to cold, with the number of exaggerated cold reactions increasing chiefly among series II subjects. In series IV, this reaction was observed only in subject A-v. During hypokinesia, phasing of the hemodynamic responses to cold was usually observed. It was characterized by the fact that more distinct cold responses occurred from the 1st through the 3rd and from the 6th through the 9th weeks of hypokinesia. In the interval from the 3rd to the 6th week of hypokinesia, the response to the cold test was weaker. It should be noted that the hemodynamic shifts in the cold test became progressively less pronounced with increasing time of confinement to bed.

Vascular tone was investigated simultaneously, before and at the 90th second of the cold test, by determining the velocity of pulse-wave propagation along vessels of the muscular (Vm) and elastic (Ve) types. The results of these studies indicated that the tonicity coefficient (Ve/Vm) had decreased in series I and II subjects. The explanation for this is that on exposure to cold, the increase in pulse-wave propagation rate along muscular-type vessels lagged behind the corresponding rate on elastic vessels. The tonicity coefficient shows no substantial change among subjects of the other series.

The heart rate did not change consistently on exposure to cold in series I-II, but a quickening of the pulse by 6-11 beats per minute was noted in series III-V. The stroke blood volume and

minute circulation volume oscillated, both increasing and decreasing. Peripheral resistance usually rose, the cardiac contractile power increased by 1.0-1.5 W, and the energy expended to transport 1 liter of blood increased by 1.5-3.0 W. The subjects showed poor subjective tolerance of cold during hypokinesia. This took the form of fear of the cold test, emotional reactions, and the wish to remove the hand from the water before the 90 seconds of exposure to cold were up. Occasionally, paradoxical vascular reactions were observed during the cold test, manifesting in a decreased rate of propagation of the pulse wave along muscular- and elastic-type vessels. These reactions were observed in series I and II subjects.

Thus, the nature of the vascular response to cold changed under the influence of hypokinesia. Among its distinctive properties, note should be taken of the appearance of an enhanced pressor reaction in some of the subjects during hypokinesia, as well as phasing in its manifestation. Repetition of the cold test during hypokinesia produced a decrease in the tonicity coefficient (Ve/Vm) and inadequate reactions in series I and II subjects. The /46 data cited indicate a disturbance of the pressor-depressor mechanisms of vascular-tone regulation that arise under the influence of extended hypokinesia.

Among the tests that we employed, special interest attaches to the Schwalm cuff test. Compression of the upper third of the thigh with the cuffs for 20 minutes to 80-85 mmHg results in stagnation of up to 700-1200 ml of blood in the veins of the lower extremities (Barcroft, Edholm, 1945). N.N. Savitskiy compares this condition with internal bloodletting. It is appropriate to note here that Schwalm proposed the test for diagnosis of hemorrhaging. The cuff test leads to collapse if there is a substantial loss of blood and the blood depots become exhausted. In Schwalm's opinion, this test causes an insignificant quickening of the pulse and a systolic-pressure decrease in healthy individuals.

In our studies, the cuff test produced insignificant hemodynamic shifts in the initial period. Pulse rate rose by an average of 10 beats/min, and there was no substantial change in arterial pressure. The stroke volume either did not change (series III) or dropped by 13-25 ml. The minute circulation volume varied in a $\pm$0.7-liter range.

The hemodynamic changes in experimental series I-III were unidirectional under the influence of hypokinesia. The minimum, average, and lateral arterial pressures rose by 5-11, 10-18, and 5-29 mmHg, respectively. In half of the cases, the maximum arterial pressure was lowered by 6-9 mmHg, and there were consistent decreases in pulse pressure (by 4-10 mmHg) and hemodynamic impulse (by 3-8 mmHg). The heart rate rose by 15-25 beats/min during a 2-minute occlusion. Stroke volume decreased by 20-60 ml

(by 35-55%), minute circulation volume by 0.9-2.5 liters (by 40%). The extent of these changes increased with increasing time in hypokinesia. Subjectively, the participants felt weak and dizzy and developed vegetative reactions (perspiration).

Among the series IV-V subjects (who had received occlusion conditioning in addition to taking physical exercises), the blood stroke volume and circulation minute volume decreased during the cuff test, as in series I-III, but the increase in cardiac frequency was smaller (by 5-12 beats/min).

The exclusion of a certain amount of blood from circulation in the Schwalm test had no significant hemodynamic effects during the initial period, apparently because blood was mobilized from the depots. Hypokinesia resulted in substantially poorer tolerance of the cuff test, as expressed in marked tachycardia and a decrease in stroke blood volume and minute circulation volume. /47
This is explained either by a disturbance to the reflex mechanisms that mobilize depot blood or by an over-all decrease in the amount of circulating blood.

DISCUSSION OF RESULTS

According to our observations, prolonged hypokinesia strengthens the influence of the sympathetic innervation on the cardiovascular system – an effect that is manifested to different degrees in the subjects of different experimental series. The intimate mechanisms of this dominance are complex and not fully understood. In explaining this phenomenon, it will be necessary to consider both the influence of uniform experimental conditions on all subjects (hypokinesia in the horizontal position) and the action of the various prophylactic measures taken. In hypokinesia, this last circumstance has substantial influence on the direction taken by the developing hemodynamic shifts. This can evidently be explained by differences in the nature of the hemodynamic changes in the various series of subjects. For concrete evaluation of the directions taken by these changes, we might refer to certain common features in series I and II subjects (reliable increase in cardiac frequency). The subjects in these series were acted upon by a common factor: strict hypokinesia. The only difference in series II is a slight increase in arterial pressure that can be explained by the use of analeptics. The changes took another direction in subjects who engaged in systematic treadmill conditioning (series III and V). According to our data, there was a reliable increase in stroke volume among these subjects. Experimental series IV occupies an intermediate position as regards the nature of the hemodynamic changes.

The resultant hemodynamic effect (circulation minute volume) depends on heart rate, systolic ejection, and the conductance of the precapillary bed.

The changes in circulation minute volume in series I and III subjects were irregular, while series II, IV, and V subjects showed an increase in circulation minute volume. In series II and IV, it increased primarily as a result of a higher heart rate, and in series V also because of an increase in systolic ejection.

During hypokinesia in the horizontal position, muscle tone and the hydrostatic pressure of the blood column on the vessels decrease. This factor is undoubtedly important. It appears that it might explain the influence of both physical and occlusion conditioning and the use of pharmaceuticals on hemodynamics. However, use of the above prophylactic measures does not completely eliminate the hemodynamic disturbances associated with hypokinesia. Note must also be taken of the change in the conditioned- and unconditioned-reflex activity function of the central nervous system and the functions of the interoceptors and analyzers, especially the vestibular analyzer (Parin, et al., 1967). /48

Thus, prolonged hypokinesia has substantial effects on the functional state of the cardiovascular system. The hemodynamic shifts that we observed were determined both by direct effects of the altered hydrostatic pressure of the blood column on the vessels and by the decrease in muscle tone, as well as by effects mediated by the central nervous system. It appears that the coordinated activity of the systematic and parasympathetic divisions of the nervous system is disturbed under the influence of hypokinesia. Reduced muscular activity has an inhibiting effect on the parasympathetic division, thus strengthening the sympathetic effects on the cardiovascular system. The physical and occlusion conditioning that was applied in the horizontal position does not fully eliminate these disturbances, since it cannot create the adequate load experienced by the human supporting-motor, cardiovascular, and nervous systems in the active vertical position.

CONCLUSIONS

1. A predominant influence of the sympathetic innervation on the cardiovascular system is observed during prolonged hypokinesia.

2. Prolonged hypokinesia changes the reaction of a man to cold; this is manifest in phasing of the reactions, weaker responses, and a decrease in the tonicity coefficient of the vessels.

3. The cuff test can serve as a tentative indicator of the compensatory capacity of the cardiovascular system during hypokinesia when a certain amount of blood is excluded from circulation.

4. Physical conditioning mitigates the deconditioning effect of hypokinesia on the cardiovascular system to some degree, but does not prevent it entirely.

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HEMODYNAMIC CHANGES DURING PROLONGED HYPOKINESIA ON THE BASIS OF THE DYE-DILUTION METHOD

A.P. Pekshev

ABSTRACT: Under the conditions of strict confinement to bed, the hemodynamic changes in the subjects usually increase with increasing time of hypodynamia. In a number of cases, however, stabilization of certain blood-circulation indices is observed, or they return to their original values in the course of the experiments; this makes it possible to speak of a certain adaptability of the cardiovascular system to the abnormal conditions of hypodynamia. Individual peculiarities make their appearance here in the hemodynamics of the subjects. Under the conditions of hypodynamia without prophylactic measures, there is a distinct decrease in stroke volume, minute heart volume, and the mass of central (intrathoracic) blood, a slight decrease in circulating plasma, an increase in the hematocrit, and an increase in the time of a complete blood-circulation cycle. If measures are taken during hypodynamia to prevent circulatory disorders (pharmaceuticals, physical exercises), there are some changes in the directions taken by the hemodynamic shifts. Here, the nature of the hemodynamic changes observed in some subjects suggests mitigation of the circulatory disturbances that arise during prolonged hypodynamia.

Experimental observations leading to the conclusion that the hemodynamic shifts under conditions of hypokinesia take certain directions have been described in the Soviet and foreign literature. A.L. Myasnikov et al. (1963) investigated the hemodynamics of healthy males who spent 20 days strictly confined to bed. They reported slackening of the pulse, a decrease in stroke volume, and a larger decrease in the minute blood volume (from 1 to 2.2 liters) among the subjects that they observed. Many authors have reported that the conditions of hypokinesia quicken the heart rate and lower the stroke and minute blood volumes (Buyanov, 1964; Buyanov, Beregovkin, Pisarenko, Slesarev, 1966, 1967, and others). Similar results are obtained irrespective of whether the subjects were /50 simply strictly confined to bed, immersed in water, or immobilized in plaster. According to N.Ya. Panferova, V.A. Tishler, and T.G. Popova (1967), prolonged limitation of muscular activity in

man also tends to quicken the heart rate, reduce the stroke volume (by 18%), and produce an even larger decrease in the heart minute volume (by 7%).

Prolonged immobilization of subjects by means of plaster casts (Deitrick et al., 1948) resulted only in a slight decrease in the volume of circulating blood (by an average of 5.4%). Lamb, Johnson, Stevens, and Welch (1964) found a lowered circulating-blood volume in 15 out of 17 subjects who were confined in cramped quarters or immobilized in chairs. They also noted a decrease in the hematocrit and in erythrocyte count. The same authors later came up with totally different results, namely increases in hematocrit and erythrocyte count. Still later, in 1965, they established that a 10-day confinement to a chair resulted in a substantial drop in plasma volume and erythrocyte mass and, consequently, in the total blood volume, as well as in an increase in the hematocrit and in cardiac frequency.

David (1961) noted that the hematocrit increased comparatively quickly, within 6-12 hours, in subjects who were immersed in water. Stevens and Lynch (1966) observed a decrease in total plasma volume only after 29 days of strict confinement to bed. Miller, Johnson, and Lamb (1964) found a decrease in plasma volume, erythrocytes, and total blood volume. Here the drop in erythrocyte count was noted only after 28 days, i.e., long after the decrease in plasma and amount of circulating blood had begun. They also noted a marked quickening of the pulse. Torphy (1966) observed an increase in the amount of central blood in subjects who were immersed in water.

Thus, according to the literature, the most significant hemodynamic shifts that are observed under the conditions of hypokinesia are quickening of the heart rate, decreases in the stroke and minute heart volumes, and an increase in the hematocrit. Little information has been given regarding changes in circulating blood mass (CBM). The purpose of our studies was to investigate the stroke and minute heart volumes (MHV), circulating blood mass, the hematocrit, the cardiac index, and the linear rate and time of a complete blood-circulation cycle (FCT) under the conditions of prolonged hypodynamia. The dye-dilution method is most suitable for determination of these hemodynamic indicators. The dye used was Evans blue (T-1824).

METHOD OF INVESTIGATION /51

Ten ml of blood were drawn from the right cubital vein of the subject under basal-metabolism conditions into a centrifuge tube containing one drop of heparin. The oxyhemograph was switched on and 4 ml of a 0.5% solution of Evans blue was introduced very quickly through the same needle without withdrawing it from the vein. The dilution curve was recorded continuously for 10 min until the time for the next venipuncture (Fig. 1). After 10 min,

10 ml of blood were taken from the left cubital vein and again placed in a test tube containing heparin. Throughout the experiment, the subject breathed pure oxygen through an airtight mask (Vesel'nikov, 1962). Blood was taken from the first tube for determination of the hematocrit by standing and centrifuging for 40 min at 2500 rpm. The smaller of the two hematocrit values was multiplied by a conversion factor of 0.96 to take account of the fact that a certain amount of plasma always remains between sedimented erythrocytes. The standard dye solution was prepared from the plasma of the first sample in a concentration of 12.5 mg/liter. Then the concentration of the dye in the plasma of the second blood sample was determined with a photoelectric colorimeter.

The circulating blood mass was determined by the formula

$$\text{CBM} = \frac{I}{C} \cdot \frac{100}{100 - H \cdot 0{,}96},$$

where I is the amount of blue introduced (20 mg), C is the concentration of the blue (in the blood) after full dilution (in mg/liter), and H is the hematocrit (in %).

The minute blood volume was determined by planimetry:

$$\text{MHV} = \frac{I \cdot 60 \cdot l \cdot 2}{S \cdot C} \cdot \frac{100}{100 - H \cdot 0{,}96},$$

where S is the area bounded by the dilution curve of first passage and l is the height of the dilution curve above the baseline at the point at which the second sample was drawn (in mm).

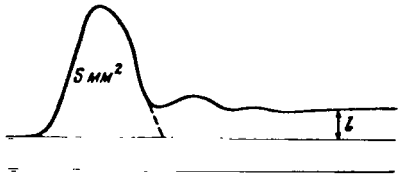

Figure 1. Dye-Dilution Curve Registered with Oxyhemograph.

Certain modifications were incorporated into the oxyhemograph that we used. The transport rate of the paper tape on which the dye-dilution curve was recorded was increased. This required introduction of a correction factor of 2 into the numerator of the MHV formula.

The central (intrathoracic) blood mass (CTBM) was calculated /52 by the formula: CTBM = second blood volume × average central blood circulation time (ACCT), where the ACCT was determined by planimetry. The full blood circulation time (FCT) was calculated by the formula

$$\text{Ve/Vm} = (\text{CBM/MHV}) \cdot 60.$$

EXPERIMENTAL RESULTS

We observed 16 healthy male subjects ranging in age from 21

to 23 years. A total of 5 series of experiments were run (see Sorokin et al., in this collection).

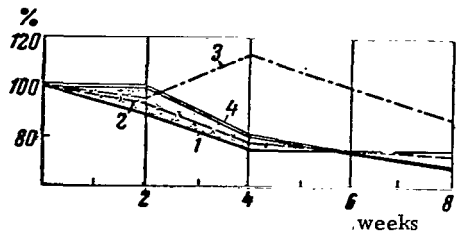

Figure 2. Variation (in %) of Stroke and Minute Heart Volumes, Circulating Blood Mass, and Central (Intrathoracic) Blood in Experimental Series I. 1) Minute heart volume; 2) stroke heart volume; 3) circulating blood mass; 4) mass of central (intrathoracic) blood.

In experimental series I, the subjects, who were strictly confined to bed, showed a marked decrease in heart minute and stroke volumes and in the mass of central (intrathoracic) blood (Fig. 2).[1] There is a distinct parallelism in the decrease of these indicators. A more pronounced decrease was observed during the first four weeks of the experiment, but at the end of the 8th week, they became more stable although remaining depressed. Such indicators as the CBM (and, accordingly, the circulating plasma mass (CPM) and the erythrocyte mass) increased slightly during the early phase of hypodynamia, but showed a distinct decrease below the initial values by the 4th week. By the end of the 8th week, the decrease in the amount of circulating plasma was found to be more conspicuous than the erythrocyte decrease. This is explained by the increase in the hematocrit, which occurred in all subjects of experimental series I. The increase in the CBM with a simultaneous decrease in minute heart volume can be explained by a sharp drop in bloodstream velocity. The full-cycle time (FCT) increased progressively in all subjects of experimental /53 series I. On the average, the FCT had risen by 16% at the end of the second week in series I subjects, and by 70% by the end of the 4th week; by the end of the 8th week of hypodynamia, a tendency to return to the initial value was observed, but the FCT nevertheless remained high by 33%. Figure 3 shows the variation of bloodstream rate during hypokinesia. Similar variations were noted in the rate of blood circulation on individual circulation paths. The circulation time on the hand-ear (H-E) path increased in all subjects. The central (intrathoracic) blood mass had decreased in absolute terms by the end of hypodynamia in all series I subjects.

By the end of the 4th week, it was observed that the CTBM/CBM ratio had decreased; this was due to both a decrease in the CTBM and an increase in the CBM. This apparently indicates a certain depoting of venous blood and a decrease in the influx of blood to the right atrium, a hypothesis confirmed by the distinct slowdown of the bloodstream (increased FCT and H-E time).

[1]The dynamics of the basic hemodynamic indices are represented as percentages of the original values, which are taken as 100%.

Along with the general directivity of the circulatory changes, individual hemodynamic peculiarities could be observed even in series I. The heart stroke volume had decreased in all four subjects by the end of hypodynamia. Yet one subject (K-s) showed increased systolic ejection at the beginning of hypokinesia. The variations of stroke volume were small in two subjects and considerable in one. By the end of the 8th week, the heart minute volume had also decreased in all subjects, but an increase in this volume was observed in the same K-s at the beginning of hypodynamia, with a simultaneous moderate increase in circulating blood mass. Individual hemodynamic peculiarities, apparently associated with the different reactivities of the subjects, were also observed in the later series of experiments, which were accompanied by the use of prophylactic measures aimed at preventing hypokinesic disorders.

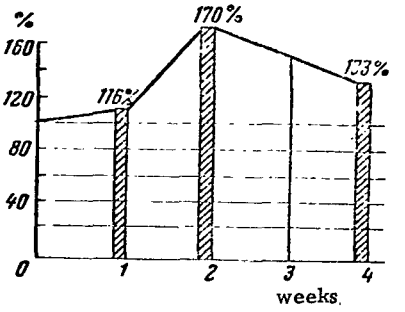

Figure 3. Change (in %) of Full Blood Circulation Time (Series I).

When the prophylactic measures were applied (physical conditioning, pharmaceuticals), the changes observed in the hemodynamic indicators were different from those seen in the control. /54

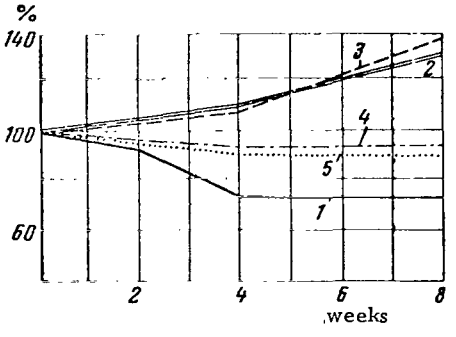

Figure 4. Changes (in %) of Heart Minute Volume in Series I-V Subjects (1-5).

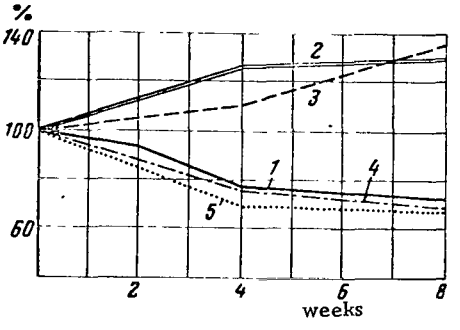

Figure 5. Change (in %) of Heart Stroke Volume in Experiments I-V (1-5). /55

Thus, heart minute volume had increased insignificantly in the series II and III subjects by the end of the 4th week of hypodynamia, but it had risen markedly by the end of the 8th week (Fig. 4). In the series IV and V subjects, the MHV must be regarded as practically unchanged, since the observed decrease does not exceed the error variations of the method. The minute circulating volume differed sharply for the subjects of control group I in

that it showed a clear decrease during hypodynamia. To judge from the curves (Fig. 4), the part played by the agents and procedures used to manipulate the state of circulation is quite obvious: they tend to increase the MHV, or in any event prevent it from decreasing. Considering the individual blood-circulation indicators, it should be noted that F-v (experiment V) showed distinct signs of overconditioning, which tended to lower the heart minute volume.

The variations of blood stroke volume parallelled those of the MHV. The decrease in systolic ejection in experiments I, IV, and V can be explained by quickening of the heart rate and the decrease in circulating-blood mass (Fig. 5).

Circulating blood mass decreased in the subjects of groups I, Iv, and V (Fig. 6). Despite physical conditioning, the CBM decrease in the group IV and V subjects was more conspicuous than in individuals of the control group (I).

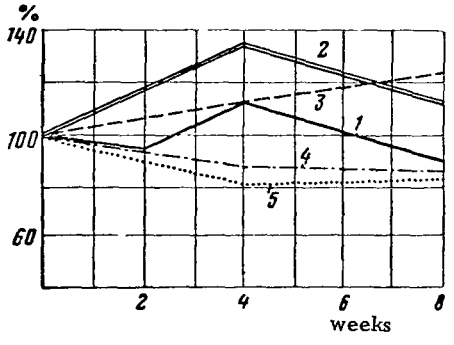

Figure 6. Change (in %) of Circulating Blood Mass in Experiments I-V (1-5).

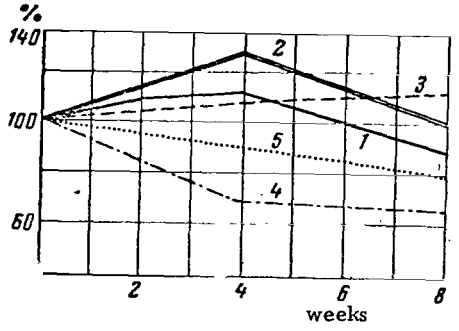

Figure 7. Variation (in %) of Circulating Plasma Mass in Experiments I-V (1-5). /56

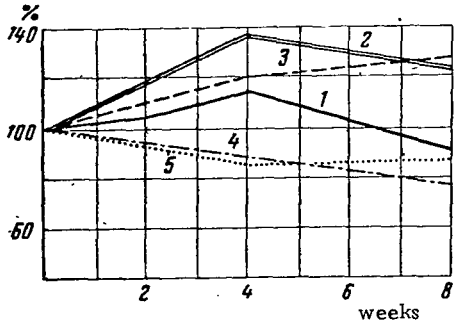

Figure 8. Variation (in %) of Erythrocyte Mass in Experiments I-V (1-5).

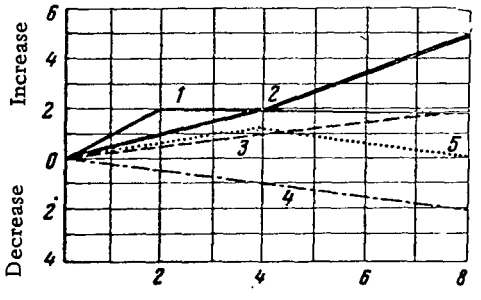

Figure 9. Variation of Hematocrit in Experiments I-V (1-5).

Circulating plasma mass decreased toward the end of the hypodynamic confinement in series I, IV, and V subjects; in series II it rose slightly and then returned to the initial figures by the end of the 8th week, and in series III a trend to increased values of this hemodynamic indicator that was noted at the beginning of hypodynamia persisted to the end of the 8th week (Fig. 7).

The erythrocyte mass showed a marked decrease only at the 8th week of hypodynamia in series I, IV, and V individuals. In series II and III, an increase in erythrocyte count was noted in the 4th week; it then decreased toward the end of hypodynamia, but did not reach the initial figures (Fig. 8).

The hematocrit indicators rose markedly in series I, II, III, and V subjects (the largest individual variations ranged from 3 to 10%); in series IV, the hematocrit was observed to have decreased by 1% at the end of the 4th week and by 2% at the end of the 8th week (Fig. 9).

The full-cycle time showed a clear increase with increasing CBM or decreasing MHV. The impression gained was that the FCT increase depends to a greater degree on the MHV decrease. However, the dependence of the FCT on CBM and MHV is less clearly in evidence under the conditions of hypodynamia than it is in persons living under ordinary conditions. The explanation for this appears to be that the relationships between such quantities as the circulating blood mass and minute heart volume are less strongly correlated under the conditions of hypodynamia than they are in persons following the ordinary life pattern. /57

In experimental series I, the central blood mass decreased with diminishing MHV and CBM. In series II-V, the CTBM changed in the same direction as the MHV and CBM. It was noted here that the size of the MHV increase exceeded the increase in CTBM, while a decrease in CTBM resulted in a sharper drop in the CBM, i.e., the influx of blood to the right atrium was obviously better in the series II-V subjects. The cardiac index varied as a function of MHV variations and remained strictly dependent on the latter quantity.

The individual data of each subject must be taken into account in analyzing the group-averaged hemodynamic indicators. This is because change in the same direction were usually observed in two subjects in each experimental series, while the third showed no change or changes in the opposite direction.

There is no doubt that restriction of motor activity and the lower hydrostatic pressure on the one hand, and the systematic application of preventive measures against circulatory disorders on the other, influence the state of the blood circulation. The possibility that the influence of physical exertion in the supine position has certain peculiarities cannot be excluded. It may be

that physical exercises taken in the horizontal position tend to produce a greater increase in the circulating blood mass and minute heart volume than exercises performed in the usual vertical position. The influence of the pharmaceuticals was also obvious. Their combined effect on the cardiovascular and central nervous systems cannot be left out of account; nor can the individual responses to the preparation, which would appear to explain the wide variations of the hemodynamic indicators. The individual peculiarities of the blood-circulation system's response to hypokinesia must also be remembered.

CONCLUSIONS

1. Under the conditions of strict confinement to bed, the hemodynamic changes in the subjects usually increase with increasing time of the hypodynamia. In many cases, however, stabilization of certain blood-circulation indicators or a return to the original values is observed in the course of the experiments, so that we may speak of a certain adaptability of the cardiovascular system to the abnormal conditions of hypodynamia. Individual peculiarities make their appearance here in the hemodynamics of the subjects. /58

2. When no prophylactic measures are taken under conditions of hypodynamia (experimental series I), there are distinct increases in stroke volume, minute heart volume, and the central (intrathoracic) blood mass, a slight decrease in circulating plasma, an increase in the hematocrit, and a lengthening of the total blood-circulation time.

3. When measures are taken to prevent circulatory maladjustments under the conditions of hypodynamia (drugs, physical exercises), there are some changes in the directions taken by the hemodynamic shifts characteristic of series I of the hypodynamia experiments. Here the nature of the hemodynamic changes observed in a number of subjects indicates a diminution of the circulatory disturbances that arise during prolonged hypokinesia.

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PHASE CHANGES IN THE CARDIAC CYCLE DURING PROLONGED HYPODYNAMIA ACCORDING TO POLYCARDIOGRAPHIC AND KINETOCARDIOGRAPHIC DATA

M.I. Tishchenko, B.A. Korolev, V.A. Degtyarev, and B.F. Asyamolov

ABSTRACT: Phase analysis of cardiac activity under the conditions of prolonged hypodynamia brings out changes in the phase structure of the cardiac cycle that are manifested in the development of a hypodynamic phase syndrome. This takes the form of shortening of the blood-expulsion and mechanical-systole phase, lengthening of the tension, isometric-contraction, and myocardial-relaxation phases and a decrease in the initial rise rate of intraventricular pressure. By the 4th week after hypodynamia, normal phase activity has been restored in the cardiac cycle. The hypodynamic phase syndrome is equally in evidence among subjects of the control group and those of the group in which prophylactic measures were taken.

The phase structure of the cardiac cycle has been studied by many authors under the conditions of hypodynamia (Mikhaylovskiy et al., 1967; Myasnikov et al., 1963; Panferova et al., 1967).

The result of these studies was identification of a hypodynamic phase syndrome characterized by lengthening of the phase of isometric ventricular contraction, shortening of the period of expulsion and mechanical systole, a decrease in the rise rate of intraventricular pressure, an increase in the myocardial tension index, etc.

The object of the present study was to investigate further the changes in the cardiac-cycle phase structure under the influence of hypodynamia and to use the phase-analysis data for comparative evaluation of the effectiveness of various prophylactic measures taken to reduce or eliminate the influence of hypodynamia: physical exercises, occlusion cuffs, pharmaceuticals.

EXPERIMENTAL METHOD

In all experimental series, the phase structure of the cardiac cycle was studied under basal conditions and in subjects at

rest after 30 minutes of relaxation. Investigations were carried out in the initial state, over the 1-2 weeks before the start of the experiments, daily during hypodynamia, and at the 1st, 2nd, and 4th weeks after hypodynamia.

The lead II electrocardiogram, the Maas-Weber first-mean-frequency phonocardiogram (70/18 Hz), the carotid-artery sphygmogram, and the kinetocardiogram were registered under basal conditions on an electrocardiograph whose strip moved at 50 mm/sec. The tachooscillogram was also registered on the mechanocardiograph. A 900-gram crystal microphone was used as the phonocardiogram pickup; it was mounted over the 4th left intercostal space on the parasternal line. The sphygmogram and kinetocardiogram were recorded from pneumographic capsules secured under elastic bandages on the projection of the carotid artery and in the region of the apical cardiac impulse.

The signal from the sphygmogram sensor was fed to a piezoelectric transducer of V.A. Elivanov's design (1965), in which capacitance shunting was used to obtain a linear frequency characteristic in the range from 0.5 to 15 Hz and a slight rise (by 20-25%) at frequencies of 20-30 Hz. The purpose of the latter was to emphasize the high-frequency components of the curve. The amplitude- and phase-frequency characteristics of the transducer used to register the kinetocardiogram appear in Fig. 1.[1] /60

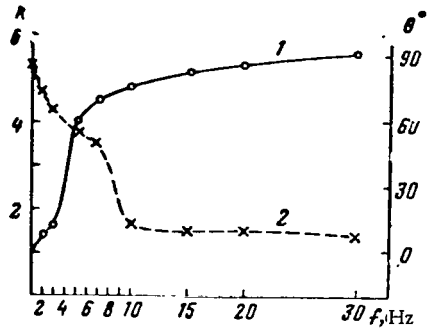

Figure 1. Characteristics of Kinetocardiograph Transducer. Amplitude-Frequency (1) and Phase-Frequency (2) Characteristics.

The inductive transducer designed by V.V. Lepeshkin and L.A. Kazar'yan, which has a resonant frequency of 100 Hz, was used as the phonocardiogram pickup in the quiescent state after 30 minutes of relaxation.

The lengths of the cardiac-cycle phases were computed from the polycardiogram by the Blumberger-Holdak method, as modified by V.L. Karpman (1965). In determining the phases from the kinetocardiogram, the relation of its elements to the times of opening and closing of the valves of the heart was taken into account.

EXPERIMENTAL RESULTS

The dynamics of the phase of asynchronous and isometric

[1]The sensor characteristics were checked with measuring equipment proposed by M.I. Tishchenko for study of ultralow [sic] mechano-electric transducers.

contraction of the ventricles and the period of expulsion as determined from the polycardiogram appears in Fig. 2. From this figure, we see that the phase structure of the cardiac cycle changes in the same direction during hypodynamia, both in the control group and in subjects who engaged regularly in physical exercises and occlusion conditioning and were given the pharmaceuticals. The isometric-contraction phase increases under basal-metabolism conditions. The increase was reliable for the subjects of series I, III, and V. A trend toward an increase was also noted in series II and IV, although it became reliable only at the 3rd and 7th weeks. The transformation phase did not change reliably in series I, III, and V subjects, but it increased by 0.005-0.012 sec ($P < 0.05$) in series II in the first week of hypodynamia. In accordance with the change in these phases, a trend toward a longer tension period, which reached 0.13-0.14 sec, was observed in all cases. /61

The expulsion period shortened as the pulse rate rose. However, the discrepancy between the actual and "ideal" expulsion periods increased from the 2nd-3rd week, reaching 0.04-0.6 sec.

As a rule, the electrical systole corresponded to the pulse frequency. The electromechanical systole was 0.04-0.06 sec shorter than the "ideal" values. The mechanical systole agreed with the "ideal" values.

During hypodynamia, the Blumberger coefficient decreased in all series by 0.4-0.8 unit, dropping to 1.9-2.0 in the series II and III subjects.

The intrasystolic expulsion index decreased in all series, with the largest drop (13%) in series I.

The intrasystolic tension index had its largest increase (7%) in series II and III, where it reached 32%.

The ratio of mechanical to electromechanical systole declined by only 2-3% in series I and II subjects.

The initial rise rate of intraventricular pressure decreased in all series. In series I and II subjects, however, it did not drop below 1000 mmHg/sec, while it reached 750-900 mmHg/sec in series III-V.

As we see from Fig. 2, the changes in the cardiac-cycle phases were undulating in nature, with their maximum manifestations in the 3rd-5th and 8th-7th weeks. The phase changes persisted during the first two weeks after the subjects got up, and only in the 4th week after hypodynamia did their durations return practically to the original level.

Study of the cardiac-cycle phases through the kinetocardiogram confirms the shortening of mechanical systole and the blood-explusion phase during hypodynamia. However, the dynamics of the ventricular isometric contraction phase was quieter (Fig. 3), and the lengthening detected on the polycardiogram was not observed. The transformation and protodiastole phases also showed no substantial changes, varying in the ranges from 0.05 to 0.6 and 0.01 to 0.02 sec, respectively. Since the changes in the period of rapid blood explusion, the phase of isometric ventricular relaxation, and the period of rapid ventricular filling can be followed on the kinetocardiogram, these phases were analyzed. The resulting data indicated that in hypodynamia, the ventricular isometric relaxation phase becomes somewhat longer, while the phase of rapid ventricular filling undergoes no substantial change. The period of rapid expulsion increased at the 3rd week and at the end of hypodynamia.

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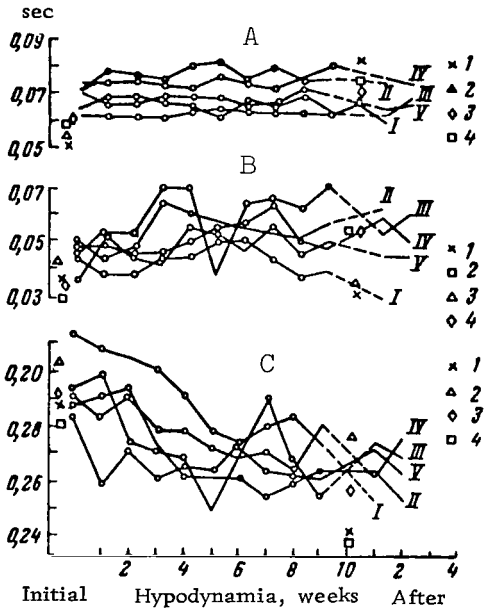

Figure 2. Variation of Asynchronous-Contraction (A) and Isometric-Contraction (B) Phase Durations and Expulsion Period (C) in Subjects of Experimental Series I, II, III, IV, and V with Hypodynamia (according to Polycardiogram) under Conditions of Basal Metabolism and During Rest after 30 Minutes of Relaxation. 1-4) Experimental Series II-V.

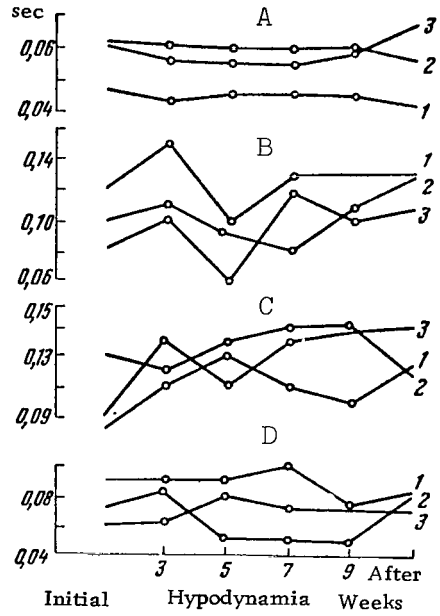

Figure 3. Duration Changes of Isometric Contraction (A), Rapid Expulsion of Blood (B), Isometric Relaxation (C), and Rapid Blood Filling of Ventricles (D) under Basal-Metabolism Conditions in Subjects A-n (1), A-v (2), and B-k (3) in Experimental Series IV and V with Hypodynamia (according to Kinetocardiogram).

DISCUSSION OF EXPERIMENTAL RESULTS /63

As we see from the results of the experiments, the phase structure of the cardiac cycle underwent quite definite changes during prolonged hypodynamia. The shortening of the phase of expulsion and mechanical systole was most characteristic. According to the polycardiogram, the isometric-contraction phase increased. Since the duration of the tension period also increased slightly, the Blumberger coefficient decreased. As we noted above, these changes are part of the phase syndrome of hypodynamia. It is important to note that they were observed in all five experimental series and, according to the data obtained, were equally in evidence in the group of control subjects and in the groups that engaged in physical exercises and occlusion conditioning and were given pharmaceuticals (securinine, caffeine, amphetamine). Thus, no doubt remains as to the prevailing influence of prolonged hypodynamia on the phase structure of the cardiac cycle.

There is no unanimous opinion among investigators as to the genesis of the phase shifts in the cardiac cycle during hypodynamia. V.L. Karpman (1965) notes that this syndrome is observed clinically in patients with cardiosclerosis, myocardial infarct, and ischemia wherever the contractility of the myocardium has been impaired under normal extracardial conditions. At the same time, he notes that functional hypodynamia may be observed in healthy persons, arising when the ventricles are not completely filled with blood (orthostatic test, Valsalva's test). A.L. Myasnikov et al. (1963) takes the view that the efficiency of the organism's regulatory systems and the energetics of cardiac muscular activity deteriorate when motor activity is limited.

According to L.A. Ioffe et al. (1960), a qualitative disturbance of cardiac-activity regulation and a decrease in the contractility of the myocardium are observed during hypodynamia.

We are inclined to concur with those authors who consider that the regulation of the organism's functional systems, including the cardiovascular, is disturbed under the influence of hypodynamia. A long time spent in the horizontal position causes a redistribution of the blood; in particular, the intrathoracic blood mass increases (Pekshev, 1967; Graveline, 1962). Many investigators have reported a change in water-salt metabolism and increased excretion of calcium, potassium, phosphorus, nitrogenous substances, and fluid with the urine (Biryukov, Kakurin, et al., 1967; Deitrick et al., 1948; Lawton, 1962).

Disturbance of water-salt metabolism, and electrolyte metabolism in particular, cannot but affect the metabolism of the heart muscle.

The phase syndrome of hypodynamia manifests in volume underloading of the heart (Ioffe, 1968), in which the general /64

peripheral resistance of the vessels and, along with it, the diastolic blood pressure increase. As was shown above, the change in the phases of the cardiac cycle persists through the first few weeks after hypodynamia and the return to the initial level occurs only toward the end of the 4th week.

CONCLUSIONS

1. During 70 days of hypodynamia, a change in the phase structure of the cardiac cycle is observed in all subjects; the phase of blood expulsion and mechanical systole is shortened, the phases of tension, isometric contraction, and relaxation of the myocardium becomes longer, and the initial rise rate of intraventricular pressure decreases.

2. The phase syndrome of hypodynamia is manifested equally in the control group and among subjects who engaged in physical exercise and occlusion conditioning and those who received medication. Normalization of the cardiac-cycle phase durations takes place only in the 4th week after hypodynamia.

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INFLUENCE OF PROLONGED HYPODYNAMIA ON HEART SIZE AND THE FUNCTIONAL STATE OF THE MYOCARDIUM

/65

I.G. Krasnykh

ABSTRACT: The thoracic organs of individuals subject to prolonged hypodynamia (70-73 days) were studied roentgenologically. It was established as a result of the study that prolonged hypodynamia leads to substantial hemodynamic abnormalities, with the result that heart size decreases by 12.9-17.9%. When complex medication was given by way of prophylaxis, the area changes were half those in the control in two subjects and the same as in the control in one subject. The contractile function of the myocardium changed in all subjects. Physical exercises combined with medication resulted in less significant changes in both heart size and heart contractile function. The extent of heart-area decrease when a set of prophylactic measures was taken (physical exercises + femoral cuffs + complex medication) was the same as in the control group in 5 out of 6 subjects, and even greater in certain individuals. The observed changes in the heart were functional in nature, and returned to normal after the subjects resumed their normal everyday activities.

We have found only occasional articles devoted to x-ray study of the influence of hypodynamia on the state of the thoracic organs in the publications available to us. Thus, Lowton's paper (1962) cites data indicating an 8% decrease in the transverse dimensions of the heart after confinement of subjects to bed. Among individuals who spent extended times (over 30 days) confined in a cramped chamber, P.N. Ivanov and A.R. Mansurov found that the area of the heart's shadow decreased and that the contractile function of the myocardium was disturbed.

In the present study, full-chest teleroentgenograms were made on all subjects in the standing position under the following technical conditions: voltage 84-88 kV, current 125 mA, skin-to-focus 2 m, exposure 0.25 sec. In addition, beginning with the second series of experiments, front-to-back x-ray kymograms were made of the heart with the subjects in the standing position during inspiration, in the stationary phase of quiet respiration, at a focus distance of 90 cm, a voltage of 76-82 kV, a current of

80 mA, and an exposure time of 2.3 sec.

Studies were made before the experiment (initial data), during the first few (2-4) days after termination of the experiments, and, for control purposes, during the course of recovery and subsequently (to 2 months).

The chest x-rays and the x-ray kymograms were subjected to comparative analysis according to a consistent plan. First the state of the heart, the major vessels, and the pulmonary tissue was studied on the full-coverage x-rays. Here, attention was given to the position of the heart, its shape, the direction of its axis, the outlines of the cardiovascular shadow, transparency of the lung tissue, the lung markings, and the structure of the roots of the lungs.

Then, using a method that has been described in detail (Ginzburg, 1933; Stumpf, 1936; Delherm, Fischold, 1936; Vladysik and Sosina, 1939; Arkusskiy, 1948; Zodiyev and Razumov, 1953; Koledinov, 1959, and others), the shape and size of the deflections were studied on the x-ray kymograms from the two contours of the cardiovascular shadow, together with measurement of the length (L), breadth (T), and area (F) of the heart. The latter was measured with a planimeter in the systole and diastole phases.

In series I of experiments, in which no x-ray kymograms of the heart were made, these heart dimensions were computed from the teleroentgenograms. The data obtained from these measurements are listed in the table.

It is evident from this table that the dimensions of the heart increased markedly during hypodynamia in both series I (control) subjects. Thus, in the x-ray examination made during the first few days after termination of the experiment, the breadth of the heart had decreased in these subjects by 6.3 and 8.2% of the initial figures, the length by 8.1 and 10.3%, and the total area by 12.9 and 17.9%. The lung areas showed increased transparency and were poor in lung markings, especially in the lateral zones of both lungs. /67 /68

X-rays taken 20 days after termination of the experiment showed that there had been almost no recovery of heart dimensions in subject M-s (the heart area was 144 cm^2, but had been 142 cm^2 a day after the experiment). Subject K-n showed a recovery of heart size, but it was still quite far below the initial data. Lung-tissue markings had recovered almost completely in both subjects.

Only subject K-n was examined at a later date. After two months, his heart had not yet reached its initial size (Fig. 1).

TABLE 1. VARIATION OF HEART SIZE UNDER THE INFLUENCE OF HYPODYNAMIA

/66

Exp. series	Subject	time of examination	Dimensions of heart		Area F, Cm^2		Change in heart area, %	
			breadth T	length L	systole	diastole	systole	diastole
I	M-s	Before experiment	14,3	16,0	—	163*		
		After experiment	13,4	14,7	—	142	—12,9	
		After 20 days.	13,6	15,0	—	144	—11,6	
	K-n	Before experiment	14,5	16,3	—	166		
		After experiment	13,3	14,6	—	135	—17,9	
		After 20 days	13,3	15,3	—	145	—12,0	
		After 60 days	13,8	15,9	—	158	—4,8	
II	B-k	Before experiment	13,1	16,3	137	147		
		After experiment	12,6	16,1	130	138	—5,1	—6,1
		After 25 days	15,0	16,0	140	148	+2,1	+0,7
	G-y	Before experiment	14,4	16,3	130	139		
		After experiment	13,3	15,0	123	132	—5,4	—5,0
		After 25 days	15,0	16,3	140	147	+7,1	+5,4
	B-y	Before experiment	14,5	15,7	135	145		
		After experiment	13,3	14,5	114	120	—15,5	—17,2
		After 25 days	14,2	16,1	135	145	±0	±0
III	M-k	Before experiment	16,1	17,2	150	160		
		After experiment	14,4	15,6	137	148	—8,7	—7,5
		After 25 days	17,0	17,9	164	170	+9,3	+6,2
	K-v	Before experiment	15,0	16,9	156	166		
		After experiment	14,0	16,0	141	150	—9,6	—10,0
		After 25 days	13,8	15,9	143	153	—8,6	—8,1
	M-k	Before experiment	15,9	16,3	146	158		
		After experiment	15,1	16,0	140	150	—4,1	—5,0
		After 25 days	15,6	16,2	140	154	—4,1	—2,5

In series II of experiments, where hypodynamia was combined with prophylactic medication, a decrease in dimensions of the heart was again noted in all subjects. During the first few days after termination of hypodynamia, heart breadth was found to be reduced by 3.8-8.4% and length by 1.2-7.6%. Heart area was down 5.1-15.5% in the systole phase and down 5-17.2% in diastole. Subject B-y showed the largest decrease, which was equal to that

TABLE (Conclusion)

/57

Exp. series	Subject	Time of examination	Dimensions of heart: breadth T	Dimensions of heart: length L	Area F, Cm^2: systole	Area F, Cm^2: diastole	Change in heart area, %: systole	Change in heart area, %: diastole
IV	B-v	Before experiment	13,8	17,2	153	162		
		After experiment	12,6	16,3	134	145	—12,4	—10,5
		After 29 days	14,3	16,6	147	155	—3,9	—4,3
	K-ya	Before experiment	16,4	18,3	185	198		
		After experiment	14,9	16,6	150	160	—18,9	—19,1
		After 29 days	15,6	17,1	175	187	—5,4	—5,5
	A-v	Before experiment	15,8	17,4	150	165		
		After experiment	15,2	15,8	122	128	—18,6	—16,3
		After 29 days	15,3	16,8	134	146	—10,8	—11,5
V	L-i	Before experiment	14,3	15,3	148	157		
		After experiment	12,6	13,2	104	108	—30	—31,2
		After 29 days	13,3	14,6	130	138	12,1	—12,1
	F-v	Before experiment	13,9	16,4	146	155		
		After experiment	12,9	16,4	142	150	—2,7	—3,2
		After 29 days	13,3	16,5	143	154	—2,0	—0,6
	A-n	Before experiment	14,5	16,4	145	158		
		After experiment	12,6	14,5	120	130	—17,2	—17,7
		After 29 days	12,4	14,6	122	131	—15,9	—17,0

*No x-ray kymogram taken; heart area determined from x-rays.

Note. The - indicates a percentage decrease by comparison with the initial data; a + indicates a percentage increase.

in the control, while G-y and B-k showed decreases smaller than that in the control. A repeated examination 25 days after the end of the experiment indicated that heart area was larger than initially in subjects B-k and G-y, and especially in the latter. The heart had recovered to normal dimensions in B-y. /69

For comparative evaluation of the functional state of the heart muscle, it should be noted that one day after hypodynamia, the deflections along the contour of the left ventricle showed the varying amplitudes and sizes characteristic for extrasystole in

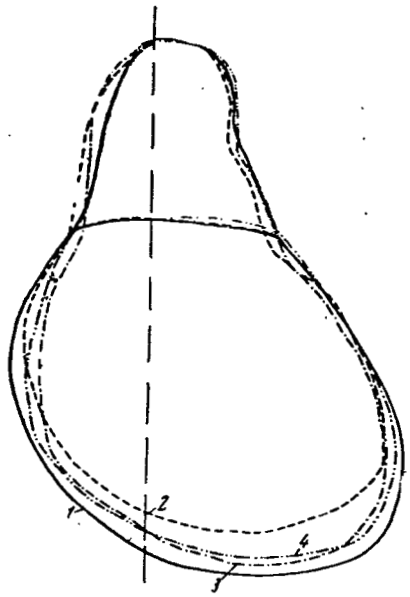

Figure 1. Heart Size of Subject K-n Before Hypodynamia and at Various Times During Hypodynamia. 1) Before experiment, F = = 166 cm^2; 2) 24 hours after experiment, F = = 135 cm^2; 3) 20 days after experiment, F = = 145 cm^2; 4) 60 days after experiment, F = 158 cm^2.

a b c

Figure 2. X-ray Kymograms of Heart Left Contour in Subject G-y. a) Normal state before experiment; b) one day after experiment, extrasystole; c) after 25 days, recovery of contractile function.

subject G-y (Fig. 2).

In subject B-y, the tips of the left-ventricle deflections were split at the beginning of the systolic knee, their amplitude and height were reduced, and there were more of them in each strip.

Heart contractile function had also changed in subject B-k. The deflections were very fine and of small height.

Subjects of this series showed practically complete recovery of myocardial contractile function 25 days after the experiment.

In experimental series III (hypodynamia + physical conditioning on the treadmill), as in the preceding series, all three subjects showed reduced heart size during the first few days after hypodynamia: an 8.7-7.5% reduction in M.M-k, 9.6-10% in K-v, and 4.1-5% in V.M-k in systole and diastole, respectively. Attention should be drawn to the fact that the area reduction was smaller in subjects of this group than in the control, especially in the case of V.M-k.

Here, functional changes in the myocardium were pronounced only in K-v, in which the deflections along the contour of the

left ventricle were finer, with small amplitude and height. After 25 days, the contractile function of the myocardium had normalized, but heart size had not recovered. Two subjects in this series (M.M-k and V.M-k) showed almost no disturbance to myocardial contractile function immediately after the experiment.

In experimental series IV (hypodynamia + bicycle ergometer + inflatable femoral cuffs + complex medication), the decrease in the size of the heart shadow was quite substantial on the second day after the experiment: 12.4-10.5% for B-v, 18.9-19.1% for K-i, and 18.6-16.3% in A-v for systole and diastole, respectively. The changes in myocardial contractile function were of the same type in all subjects and manifested in the form of fine sharp deflections, with many deflections in each strip.

In the investigation made after 29 days, heart-shadow size had recovered in all subjects of this series, but had not yet reached its original level, especially in A-v. Myocardial contractile function had also normalized by this time.

The fifth series of experiments differed from the fourth in that the subjects did their physical exercise on a treadmill. The experimental conditions were otherwise the same. On examination after the experiment, subjects L-i and A-n showed a decrease in heart-shadow size — especially in the former case, by 30% in systole and 31.2% in diastole. Myocardial contractile function had also changed in both subjects. In L-i, the amplitude of the deflections had decreased sharply, and there was a sharp increase in the frequency of the heart's contractions (Fig. 3). A-n showed almost no recovery of heart size when reexamined. Heart size recovered in L-i, but was still far below the norm. Subject F-v of this series showed insignificant changes over the time of hypodynamia. The results obtained in these experiments form a basis for the following conclusion.

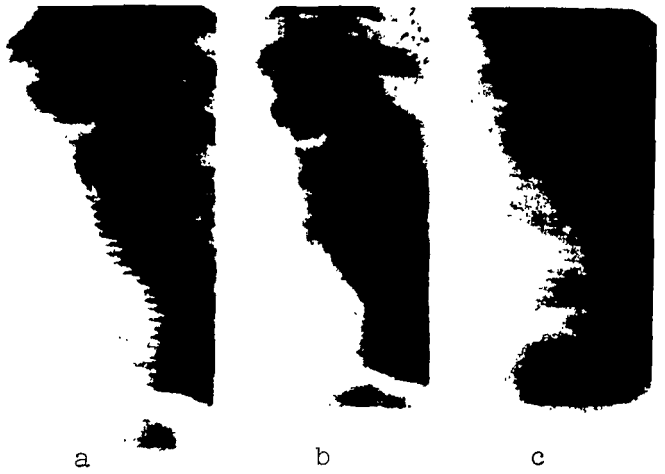

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Figure 3. X-ray Kymograms of Left Heart Contour of Subject L-i. a) Normal state before experiment; b) on second day after experiment: fine deflections with low amplitude, quickened contractions; c) after 25 days — incomplete recovery of contractile function.

Prolonged hypodynamia (70 days) results in considerable hemodynamic abnormalities in the human organism, with the result that heart size decreases. This size reduction involves all divisions of the heart visible on a direct x-ray.

The complex of medications used by way of prophylaxis (series II) had a definite influence on the condition of the heart. In two subjects out of three (B-k, G-y), the changes in heart area were roughly half those in the control, but in subject B-y they were the same as in the control.

In these subjects, recovery of the dimensions and functional activity of the heart had taken place 25 days after the return to normal activity, while the recovery process was far from complete in the control at this time.

The set of physical exercises on the treadmill (series III) also had a normalizing influence on the cardiovascular system, so that the changes in both heart size and heart contractile function were less pronounced. At the same time, we should give special emphasis to the fact that the functional abnormalities of the cardiac muscle were mildest in this group by comparison with all of the other series.

The extent of the decrease in heart area under complex prophylaxis (series IV and V) was the same as in the control in 5 out of 6 subjects, and even greater among the others. Thus, the decrease reached 30% in subject L-i. This may have been due to an added complication: toward the end of the experiment, he underwent an appendectomy, which may have aggravated the effects of hypodynamia to some degree.

The heart changes revealed by x-ray examination were functional in nature, and they returned to normal after the subjects had resumed their normal everyday activities.

This recovery was complete by the end of the first month after the experiment in the subjects of series II (who received the preventive medication) and III (who took physical exercise on a treadmill). In the control, and in groups IV and V, who received complex medication, normalization was complete by the end of the second month or the beginning of the third. /71

Despite the fact that, as we noted above, these changes were functional in nature, their persistence and duration indicate very profound and serious disturbances of myocardial function.

The cardiac-muscle disturbances that were brought out should probably be regarded as the resultant of various and profound changes brought about by prolonged hypodynamia in various functional systems. Foremost among these changes, we should take note of redistribution of the blood, loss of plasma, a decrease in

circulating blood mass, disturbance of water-salt metabolism, and a dysharmony of various neuroreflex and biochemical processes in the organism as a whole and in the cardiac muscle in particular.

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CERTAIN PECULIARITIES OF EXTERNAL RESPIRATION AND GAS EXCHANGE DURING PROLONGED HYPODYNAMIA

M.I. Mikhasev, V.I. Sokolkov,
and M.A. Tikhonov

ABSTRACT: The effects of 70-day hypodynamia on the basal metabolic level, the spirographic and pneumotachymetric indicators of external respiration, oxygenation of arterial blood, bloodstream velocity, and gas exchange under standard physical load and in orthostatic tests were studied. Basal metabolism was lowered by 5-21%, pulmonary ventilation volume was reduced, oxygen demand in the orthostatic tests was increased, and there was a substantial decrease in the tolerance of physical load. The disturbances noted were mitigated by the use of preventive measures: medication and physical exercise.

Experimental models used to simulate the effects of weightlessness on the organism include immersion of the body in liquids, strict confinement to bed, and partial or complete compensation of body weight on various types of machines. The results of studies of metabolic processes and energy expenditure made under these conditions depend to a substantial degree on the method of simulating weightlessness and therefore require subsequent refinement. /72

METHOD

Basal metabolic level and spirographic and pneumotachymetric indicators of external respiration were studied in 15 subjects during and at the end of 70 days of hypodynamia. A spirograph, a Belau apparatus, and a pneumotachymeter were used for the measurements. In addition, the oxygen saturation of the arterial blood and the linear bloodstream velocity after Matthes were determined with an oximeter.

Gas exchange and plumonary ventilation were studied by the Douglas-Holden method during orthostatic tests before and after periods of hypodynamia, in the initial supine position, in the standing position, and after return to the initial position. For certain subjects, the variations of gas exchange under physical exertion were followed by the Belau method at the beginning of the

experiment and after it was completed.

RESULTS AND DISCUSSION

In most subjects, the study of metabolic level under basal conditions that was made before the start of hypodynamia brought out no substantial deviations from the norm. In 14 subjects, basal metabolism varied from -8 to +9% around the ideal value; in only one (L-i) was it high, at +24% above the ideal value.

The nature of the basal metabolism changes during hypodynamia can be judged from the data shown in Fig. 1. To level the basal-metabolism differences related to the individual physical data of the subjects, the oxygen demand was converted to 1 m^2 of body area. The data in Fig. 1 indicate that a tendency for basal metabolism to decline was observed in all series of experiments throughout the first month of hypodynamia, that it became relatively stable at a level lower than initial during the second month, and that oxygen demand had again risen almost to the initial values at the end of the hypodynamia.

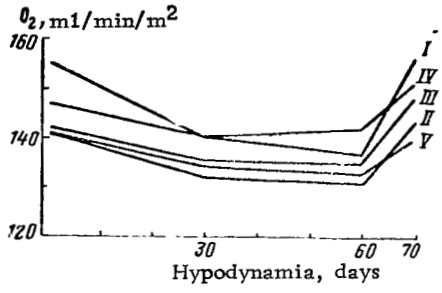

Figure 1. Oxygen Demand Under Basal Metabolism Conditions in Various Series (I-V) of Experiments (in ml/min/m^2 of body surface area).

It should be noted that the absolute decrease in oxygen demand was comparatively small, and that the observed drop in basal metabolic level varied from -5% to -21% of the ideal values, and that in two series IV subjects (A-n, F-v), basal metabolism was normal and unchanged both in the initial period and during the experiment. The most pronounced decrease in basal metabolism was observed in the series I subjects, apparently as a consequence of a decrease in the metabolic rates under the conditions of strict hypodynamia. In the experimental series in which prophylactic measures were taken, the decrease in basal metabolism was somewhat smaller, but the differences between them were not so distinct as to indicate a preference for one or another form of prophylaxis on the basis of this indicator. /73

Similar results, i.e., a drop in basal metabolism during various times in hypodynamia, were observed by Yu.V. Vanyushina et al. (1966), Lawton (1962), Pierson et al. (1965). A decrease in oxygen demand among four subjects and depression of basal metabolism by 7-22% (averaging 10%) were reported by B.S. Katkovskiy (1967) during 20 days of hypokinesia. The results of our investigations agree with these data.

The oxygen-demand increase under basal metabolism conditions that was observed in almost all subjects at the end of hypodynamia

is probably to be explained by increased emotional stress as the end of the experiment approached.

During the initial period, the basic indicators of external respiration corresponded to the ideal values. Prolonged hypodynamia produced no substantial changes in pulmonary volume, but pulmonary ventilation did decrease slightly in all experimental series (Table 1). The partial lung volumes — the reserve inspiration and expiration volumes — also remained substantially unchanged, as did vital capacity. Respiratory minute volume decreased for the most part as a result of slower and, in occasional cases, shallower breathing. As a rule, the decrease in pulmonary ventilation was accompanied by a slight rise in the oxygen utilization factor, which varied in the 44-49 range in the initial period and increased to 48-55 during hypodynamia.

TABLE 1. CHANGES IN VITAL CAPACITY (ml) AND MINUTE RESPIRATORY VOLUME (liters) DURING PROLONGED HYPODYNAMIA

/74

(Average Values)

Time of meas.	I Series		II Series		III Series		IV Series		V Series	
	MRV	VC	MRV	MRV	MRV	VC	MRV	VC	MRV	VC
Before hypodynamia	6,1	4330	5,5	4070	5,5	4200	6,5	4270	5,9	4700
2 months after hypodynamia	5,5	4200	4,9	4270	4,9	4000	6,1	4500	5,3	4800

The maximum volumetric rates of inspiration and expiration underwent practically no change in any of the subjects under the influence of hypodynamia; to some degree, this indicates preservation of respiratory-musculature tone and the absence of bronchial-capacity disturbances.

In series I and II subjects, maximum pulmonary ventilation decreased toward the end of hypodynamia, from 81 and 98 liters/min to 78 and 95 liters/min, respectively. At the same time, this indicator rose from 80 to 90 liters/min in the group that took physical exercises on the treadmill (series III).

According to the oximetry data, the oxygen saturation of the arterial blood did not change during the experiment, remaining in the 96-98% range; the Matthes linear bloodstream velocity also remained unchanged.

The dynamics of the changes in gas exchange under physical exertion after Belau were followed in only one series I subject (Ch-y). In the initial period, he did the standard physical work for 5 minutes, during which the restitution factor (the ratio of oxygen demand during exertion to the oxygen deficit) was 3.6 and

the time to eliminate the oxygen deficit was 2 minutes 24 seconds. When this test was taken on the third day after the end of hypodynamia, he was able to continue the same work for only 1.5 min, and the restitution factor dropped to 0.38 owing to a sharp increase in oxygen deficit.

On the tenth day after the experiment, the functional capacities of the cardiovascular and respiratory systems had recovered to a substantial degree: the exertion limit was 4 minutes 50 seconds and the restitution factor 3.9, but the time to cover the oxygen deficit had still not normalized, and amounted to 4 minutes 52 seconds. This time had not even recovered on the thirteenth day after the experiment, when it stood at 4 minutes 24 seconds, although the other indicators had stabilized at a level near the original.

Pierson et al. (1965) also observed an excessive oxygen deficit under physical load in their subjects after hypodynamia, and we are therefore quite willing to concur with these authors as to the need to consider the possibility of development of a large oxygen deficit in designs for life-support systems. /75

Series II-V subjects showed somewhat better tolerance of physical exertion after the experiment, but again, fitness to work had not been fully recovered 10-14 days after the experiment.

The results of many experimental studies (Vanyushina, 1963; Graveline and Balke, 1961; Graybiel and Clark, 1961, and others) indicate a decrease in orthostatic stability among subjects who had spent various times under hypodynamic conditions. This is also indicated by spaceflight practice (Berry, 1965). In the opinion of most authors, the most distinct orthostatic derangements manifest in dysfunction of the cardiovascular system (Graveline and McCally, 1962; Lamb and Johnson, 1964, and others). At the same time, study of respiratory peculiarities under orthostatic conditions is of definite interest for understanding of the etiology of these disturbances, and gas-exchange data will be most informative in this regard as an integral indicator of the relationships between the circulatory and respiratory systems, since one of the basic functions of the cardiovascular system is to supply the organism with oxygen and remove metabolites, including carbon dioxide.

A relation between the rate of metabolic processes and the work of the heart has been established by many investigators (Zaeper, 1937; Astrand and Saltin, 1961; Buyanov, 1963, and others). Hence the functional state of the cardiovascular system is to a certain degree characterized by the level of metabolism.

Table 2 presents data that characterize the changes in pulmonary ventilation volume among the subjects as they took orthostatic tests before the experiment, at the end of hypodynamia, and

TABLE 2. PULMONARY VENTILATION IN ORTHOSTATIC TESTS (M ± m)

Series	Body position	Minute respiratory volume, liters		
		before hypodynamia	at end of hypodynamia	recovery period
I	Horozontal	6,26±0,3	5,6±1,6	5,9±1,4
	Vertical	7,6±1,3	8,0±0,6	6,9±1,2
II	Horizontal	6,2±1,4	6,3±1,5	5,5±1,8
	Vertical	7,6±0,4	7,9±0,9	7,3±1,0
III	Horziontal	5,6±0,8	6,1+0,5	6,0±0,6
	Vertical	6,9±0,3	7,7±0,6	6,8±0,5
IV	Horizontal	6,6±0,5	5,6±0,8	6,5±0,9
	Vertical	8,4±0,4	7,3±0,7	8,1±0,4
V	Horizontal	6,5±1,2	4,7±0,8	6,5±0,4
	Vertical	7,3±0,6	5,8±0,2	6,9±0,4

during recovery, 15-20 days after the end of the experiment.

From Table 2, we may conclude the existence of a certain directional trend in the pulmonary-ventilation changes during orthostasis: when the subjects were shifted from the horizontal to the vertical position, their respiratory volumes increased, with the largest increase observed at the end of hypodynamia, and especially among subjects of experimental series I.

The fluctuations of pulmonary ventilation in the initial horizontal position at various stages and in the various series of experiments took various directions and do not appear to be of much prognostic value, since they are governed to a considerable degree by emotional stress associated with the impending test, rather than with changes in the level of metabolic processes. /76

TABLE 3. VARIATIONS OF OXYGEN DEMAND IN ORTHOSTATIC TESTS IN THE VERTICAL POSITION OF THE BODY AS AGAINST THE HORIZONTAL POSITION (in %)

Conditions	Series of experiments				
	I	II	III	IV	V
Before start of hypodynamia	+22	+39	+51	+24	+15
At end of hypodynamia	+66	+28	+28	+24	+21

At the same time, the abrupt change in the direction of gravity with respect to the body's longitudinal axis gives rise to considerable stress in a whole series of the organism's systems,

sometimes even in excess of its compensatory capacities. Naturally, this stress raises the metabolic level and is reflected in increases in pulmonary ventilation and oxygen demand.

Figure 2 shows oxygen-demand figures for the subjects at the transition from horizontal to vertical before and at the end of hypodynamia. The figure indicates that this transition is accompanied by an increase in oxygen demand and that this increase is larger at the end of hypodynamia. Table 3 gives relative figures for this increase.

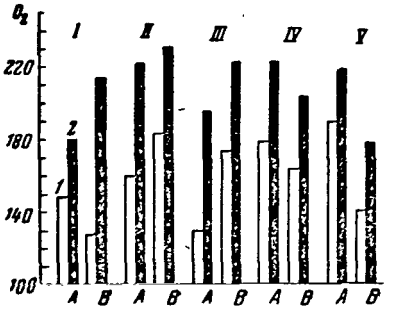

Figure 2. Oxygen Demand in Orthostatic Tests in Various Experimental Series in the Horizontal (1) and Vertical (2) Positions of the Body. A) Before hypodynamia; B) after hypodynamia.

/77

As we see from Table 3, the relative increase in oxygen demand at the end of hypodynamia increased sharply among series I subjects and to a considerably lesser degree in series V; in series IV, it did not change, and in series II and III it decreased slightly by comparison with the original figures. Thus, if it is assumed that the oxygen-demand increase in the orthostatic test correlates to some extent with the degree of functional stressing of the cardiovascular system, the series I subjects showed the poorest orthostatic stability, and this stability was higher in the experiments in which prophylactic measures were taken.

Thus, the results of the experiment to study the influence of 70-day hypodynamia on external respiration and gas exchange made it possible to bring out certain relationships in the variations of these functions, basic among which are a decrease in basal metabolic level and in the pulmonary ventilation volume during hypodynamia, as well as an increase in oxygen demand during orthostatic tests, the latter due to functional stressing of the cardiovascular system. The sharpest changes, which reflect considerable asthenization of the organism, were noted under the rigorous hypodynamic conditions of series I. Use of prophylactic measures — medications and physical exercises — made these changes less pronounced, but further comparative study of the prophylactic value of these interventions is necessary.

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NUTRITION AND METABOLISM DURING PROLONGED HYPODYNAMIA

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ABSTRACT: Examination of subjects who spent 70 days in hypodynamia indicated a decreased energy requirement coupled with a decrease in body weight. The level of protein metabolism was depressed. A negative nitrogen balance was established. The protein loss averaged 8 g/day. Calcium excretion was up 40%. The excretion of vitamins C_1, B_1, B_2, and PP with the urine decreased. The blood concentration of corticosteroids had fallen, and smaller amounts were excreted with the urine. The orthostatic test was accompanied by considerable enhancement of hypophyseal-adrenal function. Neither physical exercises nor medications prevented the metabolic disturbances.

Various nutritional and metabolic abnormalities make their appearance in a man whose muscular activity is forcibly restricted for an extended time. Experimental and clinical data indicate the development of muscular atrophy, decalcification of the bones, nephrolithaisis, venous thromboses, congestive pneumonia (Kakurin and Katkovskiy, 1966), a negative nitrogen balance (Dock, 1945; Dietrick et al., 1948; Whedon et al., 1949; Schonheyder et al., 1954; Heilskov and Schonheyder, 1955; Graveline et al., 1961; Lawton, 1962), and disturbances of mineral metabolism (Deitrick et al., 1948; Whedon et al., 1949). Studies using isotope techniques have indicated that the mechanism of negative nitrogen balance during immobilization consists chiefly in inhibition of the synthesis of tissue proteins while the rate of their breakdown remains constant (Schonheyder et al., 1954; Fedorov, Grishaninna, 1967). However, the creatinuria observed during hypodynamia (Schonheyder et al., 1954) also testifies to dystrophic processes and the breakdown of muscle proteins. The subjects of water-immersion experiments showed an increase in total blood protein concentration and a change in the protein fractions owing /79
to an increase in gamma-globulin content (Graveline et al., 1961). An increase in total blood protein (Petrov, 1962) and increased concentrations of unbound amino acids in the blood (Petrov, 1962) have been observed in subjects whose mobility was restricted. Lamb and Stevens (1965) reported considerable dehydration in an

astronaut after a spaceflight, as well as in subjects who were confined to bed. Stevens and Lynch (1965) and Ya.N. Biryukov et al.(1967) observed the same effect. It has been concluded that the most important factor in the loss of water by the organism is a change in aldosterone secretion that takes place under the influence of hydrostatic-pressure redistribution (Liddle, 1966). Many studies have been devoted to calcium metabolism and the calcium losses and bone decalcification that develop during hypodynamia (Deitrick et al., 1948; Whedon, et al., 1949; Neuman, 1963; Syc and Wedrychowski, 1965, Issecutz and Blizzard, 1966; Dick, 1966). However, as is quite correctly stated by Dick (1966) and I.S. Balakhovskiy (1967), the calcium losses during hypodynamia do not reach values that might give rise to disturbances in the supporting-motor apparatus. It is felt that the absence of longitudinal gravitational pressure is the decisive negative factor in calcium-balance regulation under the conditions of weightlessness and confinement to bed (Issecutz, Blizzard, 1966). The basic importance here is attached to reception in the bones of the lower extremities.

Prolonged limitation of mobility is accompanied by a decline in basal metabolism. During confinement in a closed cramped space, energy expenditures approach the basal metabolism (Welch et al., 1961), and this is apparently the reason for the reduced food intake (Graveline et al., 1961). Adams (1963) and Birkhead et al. (1964) state that 2500 calories, including about 75 g of protein, is an adequate intake for an astronaut on a flight of relatively short duration. Calloway (1964) considers 2800 calories and 80 g of protein as safe limits for an astronaut's daily ration.

Attempts have been made to prevent metabolic disturbances during periods of restricted mobility. Whedon et al. (1949) used an oscillating bed for this purpose. They observed that the calcium loss was reduced by half, phosphorus losses were smaller, and the disturbances of creatine metabolism were less pronounced. However, it was not possible to prevent the development of a negative nitrogen balance. Ye.N. Biryukov et al. (1967) reported less significant decalcification of the bones in subjects who performed gymnastic exercises during a period of confinement to bed. Calcium loss could not, however, be avoided, either by physical exercise on a bicycle ergometer or by combining this exercise with sitting up for brief periods (60 minutes daily), and not even 8 hours of sitting up in bed prevented hypercalciuria (Birkhead et al., 1964; Issecutz et al., 1966). All that was necessary to start a decrease in the calcium losses was to have the subjects stand up for 3 hours per day (Issecutz et al., 1966). /80

RESULTS OF OUR OWN STUDIES

During hypodynamia, the food ration in series I, II, and III contained 121 g of protein, including 100 g of animal protein, 117 g of fats, including 93 g of animal fats, and 316 g of carbohy-

drates for a total of 2880 calories. The protein-fat-carbohydrate proportions were 1:1:2.5. The ration contained vitamins in the following quantities: 0.81 mg of A, 1.25 mg of carotene, 1.35 mg of B_1, 2.8 mg of B_2, 19.4 mg of PP, and 76.6 mg of C. One-a-day supplementary synthetic vitamin lozenges were also issued; each contained 1 mg of A, 2 mg of B_1, 2 mg of B_2, 10 mg of PP, and 100 mg of C. The biological value of the ration was high, at 86 according to Mitchell and Block (against tryptophan).

TABLE 1. ENERGY REQUIREMENTS OF SUBJECTS DURING HYPODYNAMIA (Initial values were 50 for the two series)

Ten-day period	Series II	Series III	Ten-day period	Series II	Series III
2nd	45,0	41,4	5th	48,3	44,3
3rd	43,4	46,0	6th	37,0	40,8
4th	47,8	46,1	7th	25,3	27,2

Actual nutrition was studied in series II, III, IV, and V. The subjects actually required about 50 calories during the initial period, with a ideal basal-metabolism level of 25 calories/kg of body weight per day. During the second 10-day period of hypodynamia, when it was investigated, calorie requirement had dropped to a level just above 40 calories/kg of body weight per day and remained at about the same level throughout hypodynamia, dropping to 25-27 calories/kg during the last ten days. No marked differences were observed here between subjects of series II and III (Table 1).

No marked changes in the proportions of proteins, fats, and carbohydrates used were noted during hypodynamia. During this period, the subjects lost from 2 to 6.5 kg of weight in series I and from 2 to 3.5 kg in series II and III.

A new diet was introduced in series IV and V; it was distinguished by a wider variety of dishes, which were repeated in a 6-day cycle, and a more nutritious selection of products. The /81
protein sources in the diet were meat, milk, curds, eggs, cheese, cereals and bakery products and vegetables. There were 150 g of proteins, including about 60% of animal origin; 150 g of fats, including about 85% of animal origin, and 630 g of carbohydrates. The proportions between the proteins, fats, and carbohydrates were 1:1:4.2. The calorie content of the diet was about 4600 calories, of which the proteins represented 13%, the fats 30%, and the carbohydrates 57%. The vitamin value of the ration was as follows: 1.22 mg of A, 3.07 mg of carotene, 2.2 mg of B_1, 3.5 mg of B_2, 21 mg of PP, and 80 mg of C. Supplementary synthetic vitamin

preparations with the same recipe as in series I, II, and III were also issued.

It was found by keeping accounts of left-over food that the calorie requirement per kilogram of body weight per day was 55 in the initial period, 47.6 at 27-31 days, 46.6 at 54-58 days, and 43.9 at 12-16 days into the recovery period. The decreases were 14.5, 15.3, and 20.2% from the initial level, respectively. The actual protein intakes during the same periods were 114, 92, 90, and 89 g or, converted to 1 kg of body weight, 1.68, 1.38, 1.35, and 1.31 g.

The variations of body weight in series IV and V were not significant. By the end of hypodynamia, four men had lost 0.5 to 2.6 kg, for an average of 1.5 kg, while the two others had gained 0.5 kg.

METABOLISM

Methods of investigation. Nitrogen was determined after Kjeldahl, amino nitrogen after Pope and Stevens, creatinine after Braun, urea after Borodin, ammonia after Malfatti, vitamin C by the Thielmans method, thiamine after Wang and Harris, riboflavin after Ya.M. Maslennikova and L.G. Gvozdeva,[1] free nicotinic acid by the Koenig method in the Kokovikhina modification, 4-pyridoxic acid by the Haff and Perlzweig method, calcium after Pinkussen, potassium and sodium by flame photometry, blood hemoglobin after Sahli, serum protein by paper electrophoresis, blood 11-hydroxycorticosteroids (11-HCS) after DeMoor (DeMoor et al., 1960), and total 17-hydroxycorticosteroids (17-HCS) in the urine after Metcalf in I.T. Razovskaya's modification (1967).

As we see from Table 2, diuresis decreased during hypodynamia in series I from 1200 to 920 ml, or by 23.3% ($P < 0.05$). The changes were not substantial in any of the series. In series I, nitrogen excretion fell 14.2%, and by 17% in series IV and V ($P < 0.05$) (here and below, the data for series IV and V are lumped together because there were no differences between them); there /83
were no changes in series II and III. During recovery, a substantial drop in nitrogen excretion was noted in series III-V (the recovery period for series I will not be discussed in view of the small number of observations). Excretion of amino nitrogen increased by 40% in series I ($P < 0.05$), did not change in series II and III, and decreased reliably in series IV and V. During recovery, amino nitrogen decreased in series II ($P < 0.01$), but it did not change in series III-V.

Excretion of creatinine decreased in series I ($P < 0.05$), increased in series II and III ($P < 0.01$), and showed no change

[1]See "Rudovodstvo po izucheniyu pitaniya" (Handbook of the Study of Nutrition), edited by A.A. Pokrovskiy, Moscow, 1964.

TABLE 2. RESULTS OF INVESTIGATION OF NITROGEN METABOLISM DURING HYPODYNAMIA

/82

Series	Components	Initial period $\bar{X} \pm m$	Bed confinement $\bar{X} \pm m$	Bed confinement P	Recovery period $\bar{X} \pm m$	Recovery period P
I	Diuresis, ml	1200±56 (20)	920±14 (193)	<0,05	1000±113 (6)	>0,05
	Total nitrogen, g	19±1,7 (4*)	16,3±0,4 (54*)	<0,05	16,8 (2)	—
	Amino nitrogen, mg	270±5,8 (4*)	378±12,9 (52*)	<0,05	393 (4)	—
	Creatinine, g	1,67±0,03 (4*)	1,45±0,03 (49*)	<0,05	—	—
II	Diuresis, ml	1000±60 (26)	1050±17 (180)	>0,05	950±56 (27)	>0,05
	Total nitrogen, g	13,5±0,7 (18)	14,2±0,35 (48*)	>0,05	9,0±0,46 (12)	<0,01
	Amino nitrogen, mg	315±14,3 (18)	317±7,2 (48*)	>0,05	274±12,1 (12)	<0,01
	Creatinine, g	1,32±0,05 (18)	1,6±0,03 (48*)	<0,01	1,13±0,06 (12)	<0,01
	Urea, g	23,9±0,81 (15)	23,5±0,66 (42*)	>0,05	13,1±0,94 (12)	<0,01
III	Diuresis, ml	1050±44 (26)	1050±24 (180)	>0,05	950±77 (26)	>0,05
	Total nitrogen, g	13,7±0,43 (18)	13,5±0,35 (48*)	>0,05	11,9±0,78 (12)	<0,01
	Amino nitrogen, mg	316±16,8 (18)	330±9,4 (48*)	>0,05	341±46 (12)	>0,05
	Creatinine, g	1,33±0,05 (18)	1,5±0,03 (48*)	<0,01	1,3±0,01 (11)	>0,05
	Urea, g	26,3±1,52 (18)	22,9±0,93 (39*)	>0,05	20,1±1,72 (12)	<0,01
IV	Diuresis, ml	1400±49 (6**)	1250±102 (5**)	>0,05	1150±145 (4**)	>0,05
V	Total nitrogen, g	7,0±0,75 (6**)	14,7±0,13 (5**)	<0,05	12,6±0,82 (4**)	<0,01
	Amino nitrogen, mg	352±6,13 (6**)	293±3,48 (5**)	<0,05	328±14,8 (4**)	>0,05
	Creatinine, g	1,38±0,06 (6**)	1,26±0,10 (5**)	>0,05	1,25±0,092 (4**)	>0,05
	Urea, g	27,7±1,21 (6**)	24,4±2,25 (5**)	>0,05	19,9±1,33 (4**)	<0,01

*Urine from four days was combined for analysis.
**Urine from five days was combined for analysis.
Data are given for the 27th-31st days of hypodynamia; the number of observations is indicated in parentheses.

TABLE 3. RESULTS OF NITROGEN AND CALCIUM BALANCE STUDIES DURING VARIOUS PERIODS OF OBSERVATION IN SERIES IV-V

Component	Initial period (6)*	Days 27-31 of hypodnamia (5)		
	$X \pm m$	$X \pm m$	in % of initial	P
Food protein, g	114±6,86	92±5,55	−13,3	<0,05
Nitrogen in feces, g	1,3±0,094	1,2±0,15	−7,7	>0,05
Nitrogen in urine and feces, converted to protein, g	114±4,53	100±8,83	−12,3	>0,05
Food calcium, mg	1255±62	1103±68	−12,1	>0,05
Calcium in feces, mg	532±51,5	776±289	+46	>0,05
Calcium in urine and feces, mg	695±48,2	972±317	+39,9	>0,05

*The number of observations is given in parentheses for each period.

in series IV-V. During recovery, lower creatinine-excretion figures were obtained in series II; in series III, there was a return to the initial level, and the changes in series IV-V were not significant. As for urea, decreased excretion was observed in series I and IV-V, but no changes in series II and III. Excretion decreased in all series on release from bed confinement. Thus, to summarize the studies of excretion of nitrogenous components with the urine, we might draw the following outline. The most pronounced changes were observed in series I, in which prophylactic measures were taken. In this series, the excretion of total nitrogen, creatinine, and urea decreased and the excretion of amino nitrogen increased. Rather similar changes were observed in series IV-V, where the excretion of total nitrogen, amino-acid nitrogen, and urea decreased, while that of the creatinine did not change. The least significant shifts during hypodynamia were in series II and III, where only an increase in creatinine excretion was noted. During recovery, leaving series I aside, the most pronounced changes were observed in series II, in which there was a decrease in the excretion of total nitrogen, amino nitrogen, creatinine, and urea. Only a decrease in the excretion of total nitrogen and urea was observed in series III-V.

We might attempt to generalize as follows on the basis of the above data. The most distinct changes take place during hypodynamia when no prophylactic measures are taken (series I). Although it helps stabilize the excretion of nitrogenous components during hypodynamia, medication (series II) shows no protective influence during the recovery phase. Physical conditioning (series III) was found to be effective during hypodynamia and contributed to the smaller variations during recovery.

TABLE 3. (Conclusion)

Days 54-58 of hypodynamia (6)			Recovery period (4)		
$x \pm m$	in % of initial	P	$x \pm m$	in % of initial	P
90±3,64	−21	<0,01	89±3,25	−22	<0,01
1,28±0,065	−1,5	>0,05	1,62±0,14	+24,6	<0,05
98±3,39	−14	<0,05	89±5,6	−22	<0,05
1251±36	−0,3	>0,05	1341±62	−6,8	>0,05
728±51	+36,8	<0,05	751±42,5	+41,2	>0,05
959±51,1	+38	<0,01	830±37,5	+19,4	>0,05

Experimental series IV-V are most difficult to interpret. Although the same physical conditioning was used in these series as in series III, the changes in nitrogenous-component excretion were quite distinct here, except for creatinine over the entire period of observation and amino nitrogen during the recovery period. Since the only difference between these experiments and series III was in the composition of the diet, the observed changes must apparently be attributed to this factor. It appears /84 that ad libitum selection of food is not advisable. An immobilized individual with a sharp loss of appitite is in the worst possible position to select his nutrients freely according to his taste. Under such conditions, the diet should be restricted rigidly, so that the organism will obtain all of the necessary nutrient substances in rational proportions with satisfaction of the calorie requirements, which have a decisive influence on appitite.

The results of nitrogen and calcium balance studies are given in Table 3. During the initial period, the subjects were in a state of nitrogen equilibrium corresponding to 114 g of protein. During hypodynamia, a negative nitrogen balance made its appearance, corresponding to a daily average loss of 8 g of protein per subject. Nitrogen equilibrium was established 12-16 days into the recovery period, but at 89 g, i.e., below the initial level.

As we see from Table 2 [sic], the total excretion of calcium through the kidneys and intestine rises in hypodynamia, with most of the calcium excreted through the intestine. There is good reason to attribute the observed shifts in calcium excretion to its depletion from the bones. Our attention is drawn to the fact that calcium excretion decreased during recovery, although it was still above the initial level after 2 weeks.

The changes in nitrogen metabolism were accompanied by shifts in the composition of blood proteins. First of all, it should be noted that there were no differences in this respect between series II and III and series IV and V subjects, and the data have been lumped for this reason. As we know, the blood normally contains /85
6.2-8.2 g-% of total protein. As we see from Table 4, the subjects' serum-protein concentrations fell within this range during the initial period.

During hypodynamia, series II-III showed a substantial decrease in blood proteins ($P < 0.01$), and at the 10th day of the recovery period, the protein content was still below the initial level ($P < 0.02$). As we see from Table 4, the decrease in the A/G coefficient indicates that the albumins were subject to the greatest changes. In series IV-V, the opposite reaction was observed during hypodynamia: an increase in protein concentration owing to increased albumins ($P < 0.05$). It is difficult to say whether this should be related to diet composition, but in any event there is some basis for this assumption.

The hemoglobin-concentration studies indicated (Table 4) that no marked changes take place during hypodynamia; however, hemoglobin concentration does decrease ($P < 0.01$) during recovery, at least in a 2-week period. As we noted earlier, a decrease in nitrogen excretion was observed during the recovery of muscular activity, but this apparently reflects intensification of anabolic processes in the muscle tissue. If this had taken place against a background of protein insufficiency, the decrease in hemoglobin concentration would be understandable.

It is known that hemoglobin concentration declines during strict regulation of nitrogen supply and muscular conditioning, apparently to provide protein for the muscles (Yoshimura, 1961).

TABLE 4. BLOOD TOTAL PROTEIN AND HEMOGLOBIN DURING HYPODYNAMIA (in g-%) /86

Series	Component	Initial period		Hypodynamia			Recovery period		
		n	$\bar{X}\pm m$	n	$\bar{X}\pm m$	P	n	$\bar{X}\pm m$	P
II—III	Total protein	6	8,28±0,14	12	7,26±0,17	<0,01	6	7,36±0,25	<0,02
	A/G	6	1,82	12	1,33	—	6	1,5	—
	Hemoglobin	18	16,9±0,3	43	16,5±0,15	>0,05	12	15,6±0,29	<0,01
IV—V	Total protein	6	7,31±0,17	27	7,72±0,06	<0,05	6	7,45±0,1	>0,05
	A/G	6	1,36	27	1,5	—	6	1,56	—
	Hemoglobin	24	16,5±0,26	44	16,9±0,19	>0,05	12	15,5±0,12	<0,01

TABLE 5. ACTUAL INTAKE OF VITAMINS WITH FOOD (in mg) /87
(Not counting synthetic preparations; calculated data)

Period	B_1	B_2	C	PP
Initial	1,74	2,98	73	18,8
Hypodynamia (days 27-31)	1,36	2,65	58,9	16,3
Hypodynamia (days 54-58)	1,26	2,79	36,2	16,3
Recovery (days 12-16)	1,38	2,83	25,8	15,8

TABLE 6. VARIATION OF VITAMIN INTAKE (1) AND EXCRETION (2) (in % of initial value)

period	B_1		B_2		C		PP	
	1	2	1	2	1	2	1	2
Hypodynamia (days 27-31)	−10	−53,5	−7	−24	−7,5	−31,5	−8,5	−15
Hypodynamia (days 54-58)	−13	−41,4	−4	−9	−21,4	−51,4	−8,5	−22
Recovery (days 12-16)	−11	−57,5	−3,5	+20	−27	−19	−10,5	−15

TABLE 7. EXCRETION OF SODIUM AND POTASSIUM WITH DAILY URINE (in milliequivalents)

Component and series	Initial period		Hypodynamia			Recovery period		
	n	$X \pm m$	n	$X \pm m$	P	n	$X \pm m$	P
Sodium II*	24	165±6,7	48**	164±6,6	>0,05	11	178±7,4	>0,05
III	22	163±7,2	48	163±4,3	—	11	155±15,5	>0,05
Potassium II	24	65,4±2,14	48	65±3,3	>0,05	11	49,5±3,5	<0,01
III	22	61,5±3,65	48	59±1,7	>0,05	11	40,7±1,35	<0,01
Na/K II	24	2,57±0,08	48	2,53±0,047	>0,05	11	3,6±0,24	<0,01
Na/K III	22	2,67±0,14	48	2,8±0,06	>0,05	11	3,77±0,28	<0,01

*III - 3rd series.
**During hypodynamia, urine was collected over 4 days for analysis.

However, our subjects received adequate amounts of full-valued protein. Nor can the above changes be explained in terms of a concentration effect, since the hemotocrit remained

practically constant (±1% fluctuations).

A word on vitamin metabolism would appear to be in order. In all series, a decrease in the excretion of water-soluble vitamins with the urine was established during hypodynamia. These changes might be explained by the decrease in food intake. As we see from Table 5, the vitamin intake actually did decline during hypodynamia. However, the changes in vitamin excretion were too large to be explained by the reduced intake. Here the most substantial changes were observed for thiamine and ascorbic acid, something that might appear to indicate that larger amounts of these vitamins are drawn into the metabolic processes (Table 6). Let us now dwell on the results on potassium and sodium excretion with the urine (Table 7).

As we see from the data presented, potassium excretion decreased during recovery ($P < 0.01$) without any substantial changes in sodium excretion, with the result that the sodium-potassium ratio increased. This retention of potassium in the organism took place against a background of substantially reduced nitrogen excretion, and this might be attributed to intensified synthetic processes during this period. Confinement to bed was accompanied by a definite tendency to reduced excretion of 17-HCS (Table 8). Characteristically, the adrenal secretory function was still below normal 2 weeks after termination of the confinement. /88

TABLE 8. EXCRETION OF TOTAL 17-HCS WITH DAILY URINE DURING HYPODYNAMIA (in ml)

Period	n*	$X \pm m$	P
Initial	6	17,7±1,6	—
Hypodynamia (days 27-31)	6	16,2±1,3	>0,05
Hypodynamia (days 54-58)	6	16,3±1,9	>0,05
Recovery	4	13,5±2,2	>0,05

*n is the number of subjects; urine collected over 5 days during each period in series IV-V was combined for analysis.

These facts are in full agreement with the over-all decrease in metabolism that was observed during hypodynamia.

The 11-HCS concentration in the blood plasma showed a consistent and conspicuous decrease during hypodynamia (Table 9).

In this table, our attention is drawn to the sharp increase of blood corticosteriods at the 51st day of hypodynamia ($P < 0.01$).

TABLE 9. CONTENT OF 11-HCS IN BLOOD PLASMA (in μg-%)

Period	n	$x+m$	P
Initial	9	11±1,3	—
Hypodynamia, days			
5th	6	7,8±2,0	>0,05
17th	6	5,2±0,6	<0,01
33rd	5	3,9±0,5	<0,01
51st	4	19,4±1,5	<0,01
67th	5	13,3±1,4	>0,05
Recovery on 4th day	4	25,2±1,6	<0,05

This rise coincided with an orthostatic test.

A considerable rise in 11-HCS concentration — to 25.2 μg-% as against 11 μg-% in the initial period, was observed on the 4th day of the return to normalcy ($P < 0.05$).

The question as to the period during hypodynamia in which dehydration develops and the extent of dehydration, and whether it is true dehydration leading to water exhaustion or relative, i.e., /89 adaptive dehydration in response to the new hydrostatic and water-metabolism conditions, has not yet been adequately illuminated in the literature. For example, little is known concerning external water exchange and its dynamics, and this makes it difficult to solve many applied physiological-hygiene problems.

The state of external water metabolism was investigated only in subjects of experimental series IV and V, with the object of determining total water losses and structural aspects of these losses. One unique aspect of the water-metabolism experiment was that the subjects' water and calorie intakes were essentially unlimited. In taking food and water, the subjects were guided by their hunger and thirst.

The total and extrarenal water losses were calculated by the "gravimetric" method, i.e., on the basis of strict records kept over definite lengths of time on the weights of the food and water taken, the weight of urine and feces, and the changes in body weight during the same period. The water content in the feces was determined by drying them to constant weight.

Table 10 presents the results of determination of the total and extrarenal water losses and the water losses with the feces. The subjects received the same food, were under the same microclimatic conditions, and did physical work for which equal numbers of calories were required, although the forms of the activity

TABLE 10. WATER LOSSES AND THEIR STRUCTURE DURING VARIOUS PERIODS OF EXPERIMENT (Averaged data for 5 days in g/day)

/90

Series	Subject	Water loss	Initial period	Hypodynamia, days		Recovery period, days 12-16
				27-31	54-58	
V	L-i	With urine	1250	900	1100	—
	A-n		1500	1400	1200	850
	F-v		1300	1200	1300	1200
	L-i	With feces	50	22,8	52,2	—
	A-n		75	69,4	57,2	71,4
	F-v		70,5	37,2	62,6	112,0
	L-i	Extrarenally	1733	1536	1273	—
	A-n		1749	92[illegible]	1471	1650
	F-v		1661	1549	1330	1961
	B-v	Total water losses	3032	2458,8	2425,2	—
	A-v		3324	2398,4	2727,2	2571,4
	K-ya		3031,5	2786,2	2692,6	3273,0
IV	B-v	With urine	1430	1350	1350	1100
	A-v		1350	—	1400	1450
	K-ya		1550	1450	1350	—
	B-v	With feces	49,2	58,2	57,4	102
	A-v		41,0	—	40,2	74,4
	K-ya		60,0	44,7	45,8	—
	B-v	Extrarenally	1519	1067	1077	1449
	A-v		1737	—	1045	1352
	K-ya		1548	1181	1021	—
	B-v	Total water losses	2998,2	2475,2	2484,4	2651
	A-v		3128	—	2485,2	2776,4
	K-ya		3158	2675,7	2417,8	—

varied. A treadmill was used in series V and a bicycle ergometer in IV.

Comparison of the figures for total water loss in the initial period with the water losses during hypodynamia leads us to the conclusion that a lower water-metabolism level was observed in all subjects during hypodynamia. During this time, all of the subjects had smaller total water losses than during the initial period. The water losses decreased by as much as 250-925 g/day in series V, and 480-690 in IV. During recovery, the total water losses again increased for all subjects.

Turning to the quantity of water ingested before and during hypodynamia, we quickly discern a similar situation: a decreased water intake during hypodynamia (Table 10). Thus, even under conditions of unlimited water intake and a diet with more than enough calories, the transition to hypodynamia is accompanied by an "elemental" readjustment of water metabolism to a lower balance level. This is not accompanied by increased thirst.

Analysis of the water-loss structure reveals that the decrease in water losses took place through a decrease in the amount of urine excreted and through a reduction of extrarenal water losses. The shifts in extrarenal-loss volume in series IV are /91
especially indicative; here they dropped to the minimum level theoretically possible under these conditions, which is determined by water loss almost exclusively through imperceptible perspiration processes. In series V, the extrarenal losses were undoubtedly somewhat high owing to perspiration, apparently because of the specific nature of the physical load.

TABLE 11. DRINKING- AND FOOD-WATER INTAKE DURING VARIOUS PERIODS OF THE EXPERIMENT (Averaged data for 5 days in g/day)

Series	Subject	Initial period	Hypodynamia, days		Recovery period
			27-31	54-58	
V	L-i	2330	1752	1704	—
	A-n	2462	1860	2032	1968
	F-v	2552	1934	2141	2396
IV	B-v	2465	1746	1887	2034
	A-v	2424	1697	1976	2187
	K-ya	2420	1668	1671	—

Comparison of the external water-metabolism indicators at various periods during hypodynamia permits the conclusion that no further decrease in the water-balance level as compared with

the end of the first month of the experiment had taken place by the end of the second month of hypodynamia. Consequently, the dehydration processes did not progress during this period. Obviously, the basic readjustment of water metabolism to a lower balance level and, accordingly, a more active dehydration process developed during the initial phase of the hypodynamia.

The nature of the water-loss structure – quite high daily amounts of urine, low figures for the extrarenal water losses together with moderate water intake and the absence of any strong thirst throughout the experiment – provide a basis for the conclusion that the condition of the subjects under hypodynamia is not typical of true dehydration of the organism, i.e., water deficiency. This is also indicated by the results of the water-load test. On transition to hypodynamia, there is obviously a dehydration process of an adaptive nature that is governed by the new, generally easier conditions for water metabolism and by the smaller water requirements of the organism. During recovery, with the return to ordinary living, the reverse process develops: water is /92
retained in the organism and there is a transition to a higher water-balance level. Unless appropriate measures are taken to provide enough water for the organism, it is during precisely this period (the recovery) that a man may be threatened by a true water deficiency with all of its undesirable consequences, especially for the cardiovascular system and hemodynamics.

CONCLUSIONS

During hypodynamia:

1) energy requirement declines, to the accompaniment of a loss of body weight;

2) the level of protein metabolism decreases and a negative nitrogen balance is established; the protein losses averaged 8 g per day per subject;

3) calcium excretion increases, by 40%;

4) total water losses decrease (by 400-500 g/day), along with water intake (by 500-700 g/day), with establishment of water metabolism at a lower balance level; however, the dehydration process that develops at the beginning of hypodynamia is not accompanied by the phenomena of water deficit;

5) the excretion of vitamins C_1, B_1, B_2, and PP with the urine decreases;

6) the concentration of corticosteroids in the blood and the amounts excreted with the urine decrease;

7) the orthostatic test is accompanied by a significant

increase in the function of the hypophyseal-adrenal system;

8) neither physical exercises nor medication prevented the metabolic disturbances.

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MINERAL SATURATION OF BONE TISSUE UNDER CONDITIONS OF PROLONGED HYPODYNAMIA

I.G. Krasnykh

ABSTRACT: The mineral-saturation level of the right calcaneus and the first phalanx of the 5th finger of the right hand was studied by x-ray photometry in individuals subjected to prolonged hypodynamia. It was established that 70-73 days of hypodynamia reduced the amount of calcium salts in the calcaneus by an average of 11.8% and in the first phalanx of the 5th finger by 6.9%. Recovery of the calcium salts to the initial level was not complete a month later. Use of complex preventive medication did not favorably influence the level of decalcification by comparison with a control. Physical exercises prescribed for prophylactic purposes and a combination of exercise with inflatable femoral cuffs and medications resulted in smaller (by factors of 2 to 5) losses of phosphorus and calcium salts by comparison with the control.

The attention of investigators has recently been drawn to the problem of decalcification (demineralization) of bone tissue, which occurs in men and animals under the influence of weightlessness and hypodynamia.

According to Klass (1965), the Gemini 3 and Gemini 4 astronauts suffered 6.2 to 9.5% demineralization in the central segment of the calcaneus and more than 10% in the 2nd phalanx of the left fifth finger during their 4-day flights. According to P. Mack et al. (Mack, 1966), maximum decalcification reached 15.1% in the calcaneus and 23.2% in the 2nd phalanx of the 5th finger in the case of the Gemini 5 commander after 8 days in space. The maxima were somewhat smaller for the pilot. B.B. Yegorov et al. (1966) reported decalcification of the bones in dogs after prolonged spaceflight.

This paper represents an attempt to study the mineral saturation of human bone tissue under the conditions of prolonged hypodynamia by x-ray photometry. This method was described in detail by Mack et al. (1939, 1949), I.G. Sharabrin (1953, 1954), R.S. Abrosimova (1954, 1956, 1958), M.K. Groshev (1956), T.I. Alekseyeva, N.S. Smirnova, and O.M. Pavlovskiy (1963), and others.

The method consists essentially in comparative optical-density evaluations of an x-ray picture of the bone using a standard wedge, each of whose zones has a predetermined density expressed in milligrams of phosphorus-calcium salts per mm^2. This standard wedge is made from large animal bones and takes the form of a plate 10 mm wide and 100 mm long whose thickness increases linearly from 1 to 12 mm. /94

For x-ray-photometric determination of mineral saturation, an x-ray photograph was made of the right hand in ventrodorsal projection together with the standard wedge, under the following conditions: voltage 42 kV, current 45 mA, skin-to-focus distance 100 cm; exposure 0.5 sec. An x-ray of the right calcaneus was made in lateral projection at 48 kV, with other conditions the same as in the hand x-rays. Particular attention was given here to the rule of identical conditions before and after the experiment (placement, technical conditions of exposure, development, and fixing, use of x-ray films from the same series, etc.).

/95

Figure 1. X-ray of Right Calcaneus with Standard Wedge. Photometry was Done Along the Lines Indicated on the Figure.

After the x-rays had been processed, the optical densities of the bones under study were measured at various points using a microphotometer, and were then compared with the identical optical density on the standard wedge; the scale supplied with the wedge was then consulted to find the density in micrograms of phosphorus-calcium salts per mm^2 to which it corresponded.

Mineral saturation was determined in the central segment of the calcaneus along three parallel lines that cross the bone transversely (from top to bottom); a total of 45-50 points were

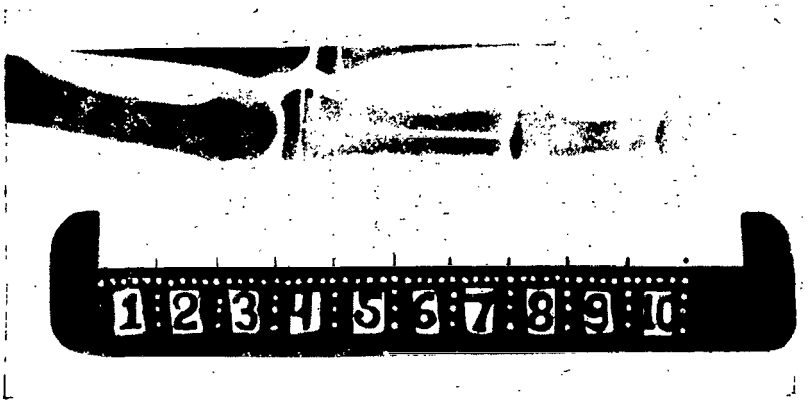

Figure 2. X-ray of Right 5th Finger with Standard Wedge. Photometry was Done Along the Lines Indicated in the Figure.

measured here, and then density was determined at 20-35 points along a diagonal line running from the posterior superior angle to the anterior inferior angle (Fig. 1).

On the x-ray of the first phalanx of the right 5th finger, measurements were made at 5 points along a line passing transversely through the proximal metaphysis and at 15 points along a line running longitudinally through the entire bone (Fig. 2).

The data obtained for all points of each bone were summed and the average densities were calculated statistically. The percentage decrease or increase in the mineral saturation of the bone with respect to the initial (pre-experiment) data was calculated with these averages as a basis.

Mineral saturation of bone tissue was studied in 14 young males who were subjected to prolonged (70-73 days) hypodynamia. A total of 5 series of experiments were run. Each of the series has already been described in detail. The bone-density determinations were made before the experiment, during the first few (2-3) days after the end of the experiment, and 20-40 days later. Data on the changes in bone-tissue mineral saturation under the influence of prolonged hypodynamia are presented in the table (see page 92).

The tabulated data indicate that in series I (the control experiment), in which mobility was strictly limited, the demineralization of the calcaneus amounted to 10.3-13.4% throughout hypodynamia (averaging 11.85%), while that in the 1st phalanx of the 5th finger was 6.7-7.1 (averaging 6.9%). /96

TABLE. VARIATION OF BONE-TISSUE MINERAL SATURATION UNDER THE INFLUENCE OF PROLONGED HYPODYNAMIA (in %)

Series	Subject	Right calcaneus		1st phalanx of right 5th finger	
		after 1-3 days	after 20-40 days	after 1-3 days	after 20-40 days
I	M-s	—10,3	—9,4	—6,7	—4,7
	K-n	—13,4	—7,2	—7,1	—2,8
II	B-k	—10,2	—6,5	—5	±0
	G-y	—11,4	—14,2	—10	—1,6
	B-y	—10,4	—3 6	—11	+4,8
III	M. M-k	—8,8	—4,1	—5,2	+3,5
	K-v	—4,2	—3,6	±0	±0
	V. M-k	—7,6	—2,9	—3	—1,5
IV	B-v	—3,1	+0,45	—7,5	—2,15
	K-ya	—2,2	—0,88	—8,9	—2,24
	A-v	—4,6	+0,92	—9,3	—3,46
V	L-i	—3,5	—0,34	—6,9	+0,99
	F-v	—1,4	±0	—3,5	+2,35
	A-n	—1,9	+1,4	—3	—1

On reexamination, which, for reasons beyond our control, unfortunately took place at different times in all series, complete recovery of bone mineral saturation to the initial level had not taken place in the control-group subjects on the 40th day, and the figures were still 5.4-7.2% low in the calcaneus and 2.8-4.7% low in the 1st phalanx of the 5th finger. No subsequent determinations were made.

In series II, in which preventive medication was administered, the losses of calcium salts were essentially the same as in the control, at 10.2-11.4% (on the average, 10.7%) [in the calcaneus] and 5-11% (averaging 8.63%) in the 1st phalanx of the 5th finger.

The demineralization of this bone was more advanced in two subjects of this group than in the control. Thirty days after the experiment, one subject showed a further decrease in mineral saturation of the calcaneus to 14.2 (as against 11.4% immediately after the experiment). /97

The two other subjects showed recovery, but the initial level had not been reached, and demineralization was still at 3.6-6.5%.

The salt level in the 1st phalanx of the 5th finger exceeded the original level by 4.8% in one subject at this time, it had reached the initial value in the second, and only in one was it slightly lower than before the experiment (-1.6%).

In experimental series III, in which there had been physical exercise on a treadmill, the mineral-salt loss from the bones was less pronounced than in the two preceding groups. The salt loss in the calcaneus was 4.2-8.8% (averaging 6.8%), and that in the 1st phalanx of the 5th finger amounted to 3-5.2% in two subjects. There were no changes in one subject. Examination after 30 days indicated that the mineral saturation of the calcaneus was still below the initial data by 2.9-4.1%. As for the 1st phalanx of the 5th finger, mineral saturation had exceeded the initial level by 3.5% in one subject, reached it another, and fallen short of it in only one individual.

In series IV, preventive measures had been taken in the form of bicycle-ergometer exercising, inflatable femoral cuffs, and complex medication. In this series of experiments, demineralization of the calcaneus reached 2.2-4.6% (averaging 3.3), and that in the 1st phalanx of the 5th finger was more advanced than in the calcaneus, at 7.5-9.3 (averaging 8.4%).

In an examination made 30 days later, there was complete recovery in the calcaneus, with a tendency to exceed the initial value, in two subjects; recovery was still incomplete in one. Recovery was not complete in the 1st phalanx of the 5th finger, and the calcium-salt level averaged 2.6% lower than the pre-experiment value.

Series V of experiments differed from IV only in the use of a treadmill for exercise. All conditions were otherwise identical. The loss of calcium salts was smallest in this case, amounting to 1.4-3.5% (averaging 2.23%) in the calcaneus and 3-6.9% (averaging 4.47%) in the 1st phalanx of the 5th finger. One month after return to normal activity, the recovery in the bone studied was complete.

In summarizing the experimental data examined above, we can state that prolonged limitation of mobility results in demineralization of bone tissue. The degree of demineralization in the calcaneus averaged 11.85, and that in the 1st phalanx of the 5th finger 6.9% in the control group. If we assume that approximately the same loss of phosphorus-calcium salts took place throughout the entire skeleton, and this assumption is quite justified, then the organism loses an average of about 110-120 g of phosphorus-calcium salts over this duration of hypodynamia (of the total amount of 1000-1200 g in the organism). Loss of this amount of calcium salts cannot be regarded as a threat to the supporting-motor functions of the human skeletal system. This is confirmed by clinical x-ray observations of the state of the skeletal system

/98

in persons who have been forced to spend long periods in the supine position (owing to illness or injury). X-ray examination indicates that they often decalcify to 50-60% in certain bones. As a rule, loss of such large quantities of salts produces a series of clinical symptoms indicating disturbance to the supporting-motor function of the skeletal-articular apparatus, which recovers, although sometimes very slowly, when the individual is returned to normal activity.

However, the importance of hypodynamic decalcification cannot be limited to its influence on the human skeletal system alone. There is no doubt that it had wider significance for a number of other organs and systems and for the organism as a whole. Thus, for example, prolonged calciuria, which inevitably accompanies hypodynamia, may lead to the formation of kidney stones. This is confirmed by Cockett et al. (1962), who observed 44 patients whose mobility was restricted for various reasons for considerable lengths of time. Fifteen of their subjects developed kidney stones, and the stones consisted of phosphorus-calcium salts in 12 cases. Lawton (1962) links formation of the stones to disturbance of water balance and lowered muscular activity.

On this basis, the development of prophylactic measures with the aim of normalizing phosphorus-calcium metabolism must be regarded as a problem of prime urgency. The effectiveness of the prophylactic complexes employed in our experiments should be evaluated from these standpoints.

Use of the pharmacological complex (series II) had no favorable influence on decalcification level by comparison with the control group.

Use of physical exercises for prophylactic purposes, and combination of these exercises with inflatable femoral cuffs and medication (series III-V) resulted in substantially smaller losses of phosphorus-calcium salts (by factors of 2-5) by comparison with the control.

Thus, the experimental data obtained indicate that a set of measures designed to maintain human motor activity, normalize hemodynamics and cardiovascular activity, and maintain tone in the central nervous system reduces decalcification of bone tissue caused by prolonged hypodynamia.

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/99

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INVESTIGATION OF CERTAIN BIOCHEMICAL BLOOD SERUM INDICATORS DURING PROLONGED HYPODYNAMIA

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N.P. Mikhaleva

ABSTRACT: A trend to lower blood-serum potassium contents was noted toward the end of a extended period of hypodynamia. A rise in the activity of alkaline phosphatases in the blood serum is reported. The activities of aspartate-aminotransferase, alanine-aminotransferase, aldolase, and creatinekinase, and the contents of sodium, phosphorus, calcium, microelements, and urea in the blood serum of the individuals studied showed no change.

Experimental and clinical studies have indicated that prolonged hypodynamia gives rise to significant metabolic shifts. Humans placed under hypodynamic conditions show a decrease in the amount of water in the organism, depressed basal metabolism, and a decrease in rest oxygen demand (Katkovskiy, 1967). This same fact has also been reported from animal experiments (Allik and Karpova, 1967).

A number of investigators have observed increased excretion of calcium, phosphorus, potassium, and sodium with the urine and higher consumption of certain vitamins (Biryukov et al., 1967; Bychkov, 1967, and others). The consequences of restriction of /100
mobility may include decalcification of the bones (Kakurin and Biryukov, 1966) and increased production of adrenocorticotropic hormone and glucocorticoids (Maystrakh, 1962). Increased excretion of the end products of protein metabolism with the urine has also been observed (Cuthbertson, 1929; Popov, 1961; Fedorov and Grishanina, 1967).

The muscular system undergoes substantial changes. Atrophy of the voluntary musculature, dystrophy of some muscle fibers, and decreased enzyme activity in muscle iissue are observed (Chagovets, 1957; Gudz', 1963; Zhdanova, 1965, and others). Together with these changes, there are substantial shifts in the system of immunobiological reactions, leading to lowered resistance (Mikhaylovskiy, et al., 1967).

In this study, the activity of a number of enzymes and the contents of certain microelements in the blood serum were investigated in healthy individuals under the conditions of prolonged hypodynamia.[1] With the onset of changes in water-salt metabolism during hypodynamia, it was interesting to investigate the contents of potassium, sodium, phosphorus, and calcium in the blood serum of the subjects. In addition, having at our disposal data on shifts in nitrogen metabolism, we considered it worthwhile to investigate the content of urea in the blood serum using the highly reliable and specific urease method.

METHODS OF INVESTIGATION

The activities of aspartate-aminotransferase and alanine-aminotransferase in the blood serum were determined by the Reitman and Frankel method (1957) with slight modifications (Korovkin, 1965).

The colorimetric method, in the modification of V.I. Tovarnitsikiy and Ye.N. Valuyskaya (1955), was used to determine aldolase activity.

The activity of creatinekinase was determined by the Enor and Rozenberg method in the modification due to L.P. Grinio and A.V. Konsistorum (1964).

Alkaline phosphatase activity was determined by the method of Klein, Read, and Babson (1960).

Emission spectral analysis on a quartz spectrograph was used to determine the microelements (Cu, Mn, Al).

Potassium and sodium concentrations were determined on a flame photometer.

Inorganic phosphorus was determined by the colorimetric method described in the handbook by S.D. Balakhovskiy and I.S. Balakhovskiy (1953). /101

Calcium was determined by complexometric titration (Kantorovich and Belinskaya, 1965).

The enzymatic urease method (Bratkovskiy and Kantorovich, 1949) was used to determine urea content.

RESULTS OF INVESTIGATION

The results of determination of the biochemical components listed above in the blood serum of the subjects in the course of

[1]The design and conditions of the experiments are reported in the article by P.A. Sorokin et al. (see this collection).

TABLE 1. RESULTS OF INVESTIGATION OF A NUMBER OF BLOOD SERUM BIOCHEMICAL INDICATORS DURING EXPERIMENTAL SERIES II

Indicator	Background study	Hypodynamia, days				Recovery period
		7-15	30	45	60-65	15-20 days
Aspartate-aminotransferase (arbitrary units)	6,2±0,39	6,6±0,55	5,3±0,09	—	3,5±0,07	4,1±0,47
Alanine-aminotransferase (arbitrary units)	2,5±0,28	2,0±0,28	2,0±0,14	—	2,3±0,41	3,3±0,47
Aldolase (arbitrary units)	12,8±0,52	11,2±1,01	8,1±0,80	—	9,3±1,59	8,7±0,83
Creatinekinase (arbitrary units)	1,0±0,01	1,1±0,07	1,2±0,13	—	0,9±0,02	1,6±0,07
Alkaline phosphatase (arbitrary units)	18,5±1,06	31,3±0,76	16,0±0,33	—	21,3±1,01	24,7±,47
Calcium (mg-%)	9,6±0,06	10,2±0,11	9,6±0,06	9,4±0,06	9,0±0,06	9,3±0,10
Phosphorus (mg-%)	4,1±0,05	5,4±0,10	4,5±0,12	5,1±0,28	5,6±0,22	5,9±0,09
Potassium (mg-%)	17,9±0,23	17,3±0,24	15,4±0,58	16,1±0,51	15,6±0,47	14,6±0,25
Sodium (mg-%)	322±0,29	324±1,80	325±0,7	294±0,7	326±4,9	298±1,0
Manganese (% of ash)	0,0002±0,00003	—	0,0001±0,00002	0,0002±0,00002	—	—
Copper (% of ash)	0,001±0,0002	—	0,003±0,0005	0,003±0,0006	—	—
Aluminum (% of ash)	0,002±0,0002	—	0,003±0,0006	0,003±0,0002	—	—

TABLE 2. BLOOD SERUM BIOCHEMICAL INDICATORS DURING EXPERIMENTAL SERIES III

Indicator	Background study	Hypodynamia, days				Recovery period
		7-15	30	45	60-65	15-20 days
Aspartate-aminotransferase (arbitrary units)	6,5±0,23	6,2±0,85	7,2±1,10	—	4,9±0,66	5,0±0,33
Alanine-aminotransferase (arbitrary units)	3,3±0,09	4,5±0,28	4,8±0,34	—	4,1±0,54	5,0±0,33
Aldolase (arbitrary units)	8,7±0,75	16,7±0,96	11,5±0,86	—	9,5±0,38	10,7±0,83
Creatinekinase (arbitrary units)	1,0±0,02	2,2±0,19	2,2±0,34	—	0,8±0,04	1,4±0,11
Alkaline phosphatase (arbitrary units)	20,5±0,35	34,7±3,66	27,7±4,21	—	26,0±2,30	28,7±2,45
Calcium (mg-%)	9,6±0,09	10,1±0,16	9,6±0,11	9,1±0,19	8,6±0,10	9,3±0,02
Phosphorus (mg-%)	4,0±0,15	5,5±0,14	3,9±0,15	4,0±0,19	5,2±0,42	5,8±0,23
Potassium (mg-%)	18,2±0,22	17,0±0,27	16,4±0,55	15,3±0,03	15,7±0,19	14,5±0,02
Sodium (mg-%)	329±4,5	328±3,5	330±3,2	293±1,8	325±5,3	304±1,3
Manganese (% of ash)	0,001±0,00002	—	0,0002±0,00002	0,0002±0,00003	—	—
Copper (% of ash)	0,003±0,0006	—	0,004±0,00002	0,002±0,00001	—	—
Alumimum (% of ash)	0,002±0,0003	—	0,002±0,0001	0,002±0,0005	—	—

TABLE 3. RESULTS OF DETERMINATION OF A NUMBER OF BLOOD SERUM BIOCHEMICAL INDICATORS IN THE COURSE OF EXPERIMENTAL SERIES IV

Indicator	Background study	Hypodynamia, days				Recovery period
		7-15	30	45	60-65	15-20 days
Aspartate-aminotransferase (arbitrary units)	5,4±0,70	6,2±0,25	3,2±0,18	—	4,7±0,69	4,5±0,35
Alanine-aminotransferase (arbitrary units)	2,0±0,28	3,2±0,53	4,7±0,18	—	4,2±0,09	3,0±0,01
Aldolase (arbitrary units)	4,8±0,19	7,0±0,47	5,2±0,18	—	4,5±0,72	8,5±0,35
Alkaline phosphatase (arbitrary units)	15,7±0,96	25,3±2,16	22,0±2,12	—	25,3±1,06	35,7±0,70
Urea (mg-%)	33,1±1,51	32,8±0,23	28,0±1,91	36,6±1,20	32,3±1,03	34,5±0,51
Calcium (mg-%)	10,3±0,24	10,4±0,10	10,1±0,07	10,6±0,03	10,2±0,06	10,0±0,05
Phosphorus (mg-%)	4,3±0,14	5,2±0,35	4,9±0,01	5,6±0,07	5,0±0,08	5,2±0,01
Potassium (mg-%)	17,4±0,07	15,7±0,35	19,7±0,56	15,7±0,51	16,5±0,06	16,8±0,39
Sodium (mg-%)	349±2,2	326±0,7	310±1,1	375±9,7	312±1,1	343±0,5

TABLE 4. RESULTS OF DETERMINATION OF A NUMBER OF BLOOD SERUM BIOCHEMICAL INDICATORS DURING EXPERIMENTAL SERIES V

Indicator	Background study	Hypodynamia, days				Recovery period
		7-15	30	45	60-65	15-20 days
Aspartate-aminotransferase (arbitrary units)	4,5±0,37	4,7±0,38	4,5±0.73	—	3,2±0,18	4,0±0,70
Alanine-aminotransferase (arbitrary units)	4,2±1,01	2,3±0,19	5,8±0,48	—	2,5±0,35	2,2±0,18
Aldolase (arbitrary units)	5,0±0,52	7,2±0,09	7,5±0,60	—	4,2±0,35	7,0±0,70
Alkaline phosphatase (arbitrary units)	17,3±1,95	29,0±1,34	29,0±1,85	—	32,0±0,38	35,0±0,67
Urea (mg-%) . . .	30,1±1,05	31,6±0,93	24,0±0,88	36,9±2,68	32,7±0,28	35,7±0,28
Calcium (mg-%) . . .	10,1±0,12	10,8±0,03	9,9±0,18	10,8±0,21	10,3±0,11	10,2±0,01
Phosphorus (mg-%). . . .	5,1±0,18	4,4±0,08	4,8±0,12	5,1±0,18	5,2±0,18	5,1±0,02
Potassium (mg-%)	17,4±0,23	16,0±0,68	17,1±0,72	15,0±0,42	15,9±0,25	18,3±0,11
Sodium (mg-%)	340±1,5	330±2,2	323±3,3	366±0,5	333±0,5	342±1,1

experimental series II and III are listed in Tables 1 and 2.

As we see from Tables 1 and 2, the activities of aspartate-aminotransferase, alanine-aminotransferase, aldolase, and creatine-kinase, i.e., enzymes that participate in transamination, glycolysis, and transphosphorylation processes, undergo practically no change during extended hypodynamia. The minor variations in enzyme activity that were observed in the course of the experiment are within normal limits.

A rise in the activity of alkaline phosphatase in the blood serum was observed in both series II and III toward the end of the third week of prolonged hypodynamia and during the recovery period.

The contents of calcium, phosphorus, sodium, and the microelements (copper, manganese, aluminum) varied within the normal range in all subjects in series II and III.

Toward the end of the prolonged hypodynamia, a certain trend toward lower blood-serum potassium figures was observed. A statistically reliable ($P < 0.05$) potassium decrease was noted in both subject groups during the recovery phase.

Tables 3 and 4 present the results of determination of the series of blood serum biochemical components in experimental series IV and V.

As we see from Tables 3 and 4, the activities of aspartate-aminotransferase, alanine-aminotransferase, and aldolase in the blood serum remained within the normal range throughout the period of study in experimental series IV and V.

During the extended hypodynamia and during recovery, a statistically reliable ($P < 0.05$) increase in alkaline phosphatase activity was noted.

No shifts were observed in the potassium, sodium, calcium, phosphorus, and urea contents of the blood serum (Tables 3 and 4). The trend toward lower potassium concentrations in the blood serum that we noted in experimental series II and III was not observed under the conditions of series IV and V.

DISCUSSION OF RESULTS /106

It has been reported by a number of investigators that catabolic processes are intensified during prolonged hypodynamia and that breakdown of tissue proteins and muscle proteins in particular is observed. It is also known that potassium, which is for the most part an intracellular cation, is excreted from the organism at increased rates during breakdown of tissue proteins, with 3 milliequivalents (120 mg) of potassium appearing for each gram of nitrogen (Vel'tishchev, 1967). It appears that this fact

might explain the slight decrease in blood-serum potassium toward the end of the long hypodynamia (60 days) in series II and III.

The blood-serum potassium content did not change in series IV and V, possibly because of the differing experimental conditions, and especially the intensified physical conditioning during the experiment.

In all four series (II-V), increased alkaline phosphatase activity was observed in the blood serum during prolonged hypodynamia and recovery.

It is customary to assume that blood-serum alkaline phosphatase originates chiefly from the skeletal system. The serum contains phosphatase with a pH optimum of about 9.0, whose immunochemical properties are similar to those of the enzyme found in the bones.

It can therefore be assumed that the increased activity of alkaline phosphatase in the blood serum during hypodynamia is associated primarily with a higher rate of arrival of the enzyme from the skeleton, as is the case in a number of bone-tissue diseases.

This does not, however, exclude another hypothesis. The increase in alkaline phosphatase activity during hypodynamia, as in rickets, can be regarded as a compensatory reaction that tends to offset the deficiency of phosphorus-calcium complexes in the bone tissue[2] by enzymatic splitting of organic phosphates. However, we must not overlook the fact that there is, as a rule, no increase in blood-serum alkaline phosphatase activity in osteoporosis (Shcheklik, 1966). Thus, the true cause of the slight increase in alkaline phosphatase activity during prolonged hypokinesia still remains unclear. /107

CONCLUSIONS

1. Toward the end of a period of prolonged hypodynamia (experimental series II and III), a trend toward lower potassium contents in the blood serum is noted.

2. Increased activity of alkaline phosphatase in the blood serum is observed during prolonged hypodynamia.

3. Under the conditions of this experiment, there were no changes in aspartate-aminotransferase, alanine-aminotransferase, aldolase, or creatinekinase activity or in sodium, phosphorus, calcium, microelement (Cu, Mn, Al) or urea content (series IV and

[2]We recall here that literature sources indicate a certain decalcification of the bones as a consequence of prolonged hypokinesia.

V) in the blood serum of the subjects studied.

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UREA CONTENT IN THE BLOOD DURING PROLONGED LIMITATION OF MOBILITY

/108

T.A. Orlova

ABSTRACT: Blood urea content was studied in 19 subjects of a 70-day hypodynamia experiment to determine whether increases previously observed in 15-30-day experiments normalize over longer periods of restricted mobility. The results indicate that the effect is nonpathological, that normalization does occur, and that the most probable cause of high blood urea is renal insufficiency rather than increased nitrogen intake or tissue protein breakdown.

The Voskhod 2 cosmonauts were found to have high blood urea contents (Balakhovskiy et al., 1965). This increase might be due either to disturbance of kidney function or an increased rate of tissue breakdown. Although the normal figures for total nitrogen excreted with the urine suggest that there was no rapid tissue breakdown during the flight, it is necessary to acquire additional data that will, even if they do not fully explain the mechanism of this increase, at least confirm the fact and permit identification of some single flight factor to which they are most closely related. To judge from available data (Fedorov et al., 1967) on negative nitrogen balance during immobility, it is precisely the restriction of cosmonaut motor activity during flight that causes the accumulation of urea in the blood. To confirm this hypothesis, blood urea content was studied in 10 subjects who spent 15-30 days in cramped chambers under conditions of restricted mobility. Blood was taken once or twice before the start of the experiment, on the 3rd or 4th day in the chamber, on later days during the experiment, and 3-4 days after its completion. Urea was determined by the reaction with diacetyl monoxime in an acidic medium (Orlova, Balakhovskiy, 1968). The studies indicated that, in spite of the normally wide variations in urea content between different individuals and at different days of the background examination for the same individual, there was a consistent increase in its content during the experiment, to a maximum reached on the 15th-17th day. In some subjects, this increase had occurred as early as the 3rd or 4th day and persisted at the same level to the end of the experiment. In some cases, urea content decreased, approaching the initial level, toward the 30th day. This obviously indicates that the organism manages to adapt to the new, unfavorable situation over this comparatively long period of time. However, even in those cases in which the return to the preexperimental values was not complete by the 30th day, urea content

settled at the usual level characteristic for each subject within 3-4 days after completion of the experiment. Such rapid normalization of the process indicates that the described changes were not pathological in nature. Thus, the earlier studies confirmed the fact that urea accumulates in the blood when motor activity is restricted.

Interest therefore attached to determining whether urea accumulates in the blood in longer experiments with more severely restricted mobility. /109 For this purpose, blood urea content was studied in 4 of the subjects in experimental series IV and V, which are described in the present collection. Blood was taken twice - before and after the experiment. The results indicated that the changes in urea content at the end of the experiment had not all taken the same direction: there was a slight increase in two subjects and a decrease in the other two. On the average, the urea content in the blood had not changed after the experiment. It appears that all changes are given time to normalize over the long period involved.

These studies indicate that an increase in blood urea content intervenes when motor activity is restricted and usually normalizes by the end of a long sojourn under conditions of hypodynamia. This increase may be a consequence of increased nitrogen content in the food, intensified tissue breakdown, or disturbance of kidney function. Since the first two possibilities appear to be excluded, the indication is that it results chiefly from renal functional insufficiency. The final answer to the question must await additional experiments in which more specific methods are used to determine urea and there are other supplementary studies.

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COAGULABILITY OF BLOOD DURING PROLONGED HYPODYNAMIA ACCORDING TO THROMBO-ELASTOGRAPHIC DATA

Ye.I. Dorokhova

ABSTRACT: Prolonged hypodynamia was accompanied by the appearance of a general hemophilic reaction of the blood. The partial blood coagulation reactions varied in the opposite direction. Physical exercises reduced the hemophilic shifts. Combining physical exercises on a treadmill or bicycle ergometer with occlusion conditioning slightly reduced the antihemophilic effect of the physical exercises.

The literature contains very few reports on changes in blood coagulation during hypokinetic states. The most detailed investigation was made by Ye.I. Chazov and V.G. Ananchenko (1963), who obtained data indicating a hemophilic blood reaction and, in particular, hypocoagulable thromboelastograms, in experiments on healthy subjects. /110

With the object of studying blood coagulation, we ran four series of experiments on 12 subjects who were placed under conditions of prolonged hypodynamia (series II-V, see Sorokin et al., this collection).

We studied the state of the blood coagulating system through an integral indicator, the thromboelastogram (TEG), using the Hartert method with a thromboelastograph. A parallel study was made of the coagulogram, including determination of partial indicators of the blood coagulating and anticoagulating systems: the Poller heparin tolerance of the plasma, the Howell plasma recalcification time, Rutberg fibrinogen content, Tugolukov prothrombin index, fibrinolytic activity and clot retraction after Kotovshchikova.

The studies were made in the initial period, in the 2nd, 4th, 6th, and 9th weeks of strict confinement to bed, and during recovery. The test results indicated that the "R" period was distinctly longer during the first two weeks of hypodynamia, i.e., a hemophilic (hypocoagulable) coagulation reaction of the blood was observed. With continuing hypodynamia, the hemophilic reaction became stronger in all subjects (Fig. 1). Our data agree with the observational results of Ye.I. Chazov and V.G. Ananchenko.

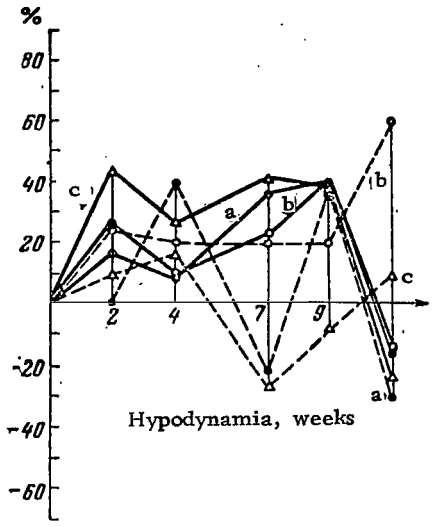

Figure 1. Variation (in %) of Certain Thromboelastogram Indicators in Subjects B-k (a), B-y (b), and G-y (c) of Experimental Series II. The Solid Line Indicates Reaction Time, the Dashed Line Clotting Time, and the Last Point the Recovery Period.

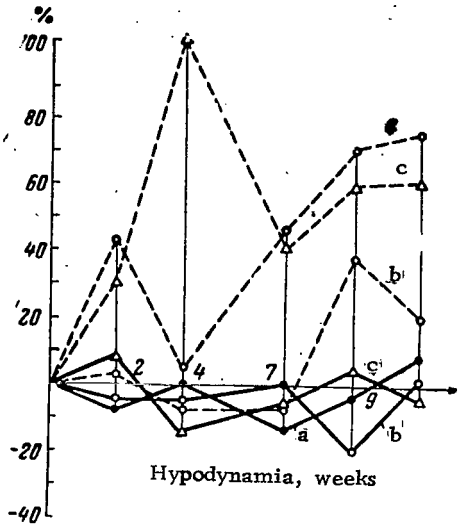

Figure 2. Variation (in %) of Certain Thromboelastogram Indicators in Subjects K-v (a), V.M-k (b), and M.M-k (c) of Experimental Series III. The Solid Line Indicates Reaction Time, the Dashed Line Clotting Time, and the Last Point the Recovery Period.

The clotting time "K" was found to be a more labile index to the blood-coagulation process. Nevertheless, it also increased in two subjects, consistent with the changes in "R."

The elasticity, or strength, of the blood clot showed a distinct decrease in one subject of this group (G-y) and practically no change in the other two.

During recovery, the hemophilic reaction was supplanted in two subjects (B-k, B-y) by a thrombophilic (hypercoagulable) reaction. Blood coagulability normalized in one subject (G-y). The progressive increase in the hemophilic reaction during hypodynamia and during the recovery phase provides a basis for the conclusion that the pharmacological prescriptions used had no substantial influence on the basic blood-coagulation processes.

The data obtained in experimental series III on subjects who exercised on a treadmill in the horizontal position were different. In two subjects (K-v, V.M-k) of this group, the TEG "R" time became shorter, i.e., coagulation of the blood was accelerated, beginning distinctly at the 2nd week of confinement to bed. These

changes subsequently persisted with minor fluctuations around the same level until the 9th week of hypodynamia (Fig. 2). During recovery, the blood-coagulation indices returned to their initial values, and the reaction time even dropped slightly below the initial values, i.e., blood coagulability had decreased in these subjects. In one subject (M.M-k), the same changes were observed, but they arose somewhat later, at the 4th week, and disappeared in the 9th week. /113

Despite the acceleration of the processes leading to the start of coagulation (the TEG "R" time), the clotting period (the TEG "K" time) was considerably longer (by 1/3 to 2/3 of the original time) in the three subjects of this group during hypodynamia. The retardation of clotting progressed with time under hypodynamia, and persisted clearly into the recovery phase, i.e., after the subjects had resumed motor activity. As for the strength or elasticity of the blood clot (the quantity "E" of the TEG), this indicator was observed to decline, in spite of certain fluctuations, in all three subjects of this group. During recovery, clot strength again rose and even slightly exceeded the original value.

/112

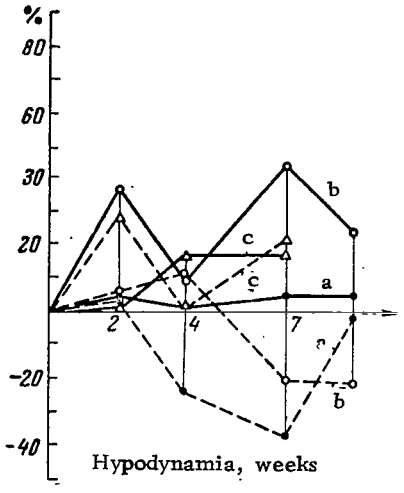

Figure 3. Variation of Thromboelastogram Indicators in Subjects K-ya (a), B-v (b), and A-v (c) in Series IV. The Solid Line Indicates Reaction Time, the Dashed Line Clotting Time, and the Last Point the Recovery Period.

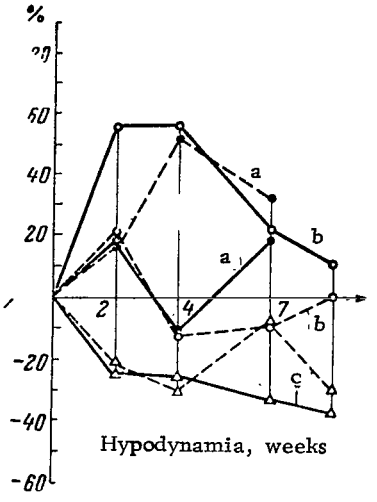

Figure 4. Variation of Certain Thromboelastogram Indicators in Subjects A-n (a), F-v (b), and L-i (c) of Series V. The Solid Line Indicates Reaction Time, the Dashed line Clotting Time, and the Last Point the Recovery Period.

Thus, a thrombophilic tendency appeared in the coagulating property of the blood under physical exertion.

A lengthening of the "R" time was recorded in two subjects (K-ya, B-v) in experimental series IV (Fig. 3). The "K" time increased slightly in two cases (K-ya, B-v) and decreased in one (A-v). There were no significant changes in clot elasticity.

In series V, instead of the shortening of the "R" time that had been observed in series III, all three subjects had longer "R" periods, and this condition persisted into the recovery phase (Fig. 4). Contrary to the result obtained in the preceding group, clotting time decreased in two subjects (A-n, F-v) and remained short in the recovery period; it increased in one subject (L-i). There were no significant changes in clot elasticity.

If we assume that physical exercising on the treadmill and the bicycle ergometer give rise to physiological and biochemical shifts of the same direction, occlusion conditioning tends to offset the thrombophilic effect of the physical exercise. Thus, the blood-clotting indicators were "closer" to "pure hypodynamia" in the subjects who received occlusion conditioning than in subjects who engaged only in physical conditioning.

Interest attaches to data characterizing the partial components of the blood's anticoagulation and coagulation systems.

Plasma heparin tolerance increased considerably among the subjects who exercised on the treadmill and this condition persisted through to the recovery period. These data correlate with the "R" changes described above. The amount of fibrinogen increased in all three subjects of this group. This increase persisted through to the recovery phase, and this may also have contributed to the shorter "R" on the TEG's. During hypodynamia, the fibrinolytic activity of the blood decreased progressively in one subject (V.M-k), while changes were noted in both directions in the other two. The prothrombin index showed a clear increase in all three subjects, and this may, of course, have influenced the rate of the blood coagulation reaction. The plasma recalcification time oscillated quite widely, but remained within normal limits. /114

Thus, the indicators that characterized the individual links in blood coagulation varied in the direction corresponding to a general tendency toward thrombophilic changes in the "R" period in the group of subjects who engaged in physical exercises on the treadmill; in our opinion, this indicates a general antihypokinetic or kinetic effect of physical exertion.

The "R" changes were similar in the series IV and V subjects; it therefore appears admissible to combine the partial blood-coagulability indicators.

Plasma tolerance to heparin increased in all six of these subjects, indicating a decrease in the active heparin

concentration of the plasma. The quantity of fibrinogen increased more often than not. The variations of the prothrombin index took either direction and were not as significant as in series III. In analyzing the partial blood coagulation factors for series IV and V subjects, therefore, we can single out two groups of criteria: 1) an increase in plasma tolerance to heparin and an increased quantity of fibrinogen; 2) a decrease in the prothrombin index and an increase in fibrinolytic activity.

The data given above provide a basis for perceiving a hypodynamia-connected reaction that is common to the three (III-IV) [sic] series of experiments, namely a reaction of the thrombophilic series (increased plasma heparin tolerance, increased quantity of fibrinogen). The opposite reactions (lower prothrombin index and increased fibrinolytic activity) noted in series III-V subjects were apparently the reason for the different directions taken by the changes in the TEG "R" period.

A confirmation for the above is found in the data obtained for persons who took medication. All of the subjects, like those of the other groups, showed increased plasma heparin tolerance. Fibrinogen concentration increased sharply in two of them (B-k, B-y). In addition, a decrease in the fibrinolytic activity of the blood was noted in all three subjects. The increase in plasma recalcification time confirmed the longer TEG "R" periods. Consequently, in this group, which can be regarded with a certain license as a control ("pure hypodynamia"), the background of the integral hemophilic shift was relieved by opposite trends in specific reactions (increased plasma heparin tolerance, increased fibrinogen, lowered fibrinolytic activity). /115

CONCLUSIONS

1. Prolonged hypodynamia is accompanied by the appearance of a general hemophilic blood reaction (lengthening of "R" and "K," decrease in "E" on TEG's). The partial coagulation reactions of the blood change in the opposite direction.

2. Physical exercise on a treadmill reduces the hemophilic shifts during hypodynamia.

3. The combination of physical exercises on a treadmill or bicycle ergometer with occlusion conditioning tends to mitigate the antihemophilic effect of the physical exercise to some degree.

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RESISTANCE TO INFECTION UNDER CONDITIONS OF HYPODYNAMIA

B.A. Chukhlovin and S.A. Burov

ABSTRACT: Changes in both the nonspecific resistance of the organism to infection and specific immunological reactivity took place under conditions of prolonged hypodynamia. These changes may tend to increase the activity of conditionally pathogenic and saprophytic automicroflora vegetating in the organism, and may also contribute to activation of latent infections or the propagation of an agent introduced from the outside.

Attention was drawn in the very first studies devoted to the influence of hypodynamia and other factors of extended spaceflight on humans to asthenization of the organism and a decrease in certain indicators of natural resistance to infection (Borshchenko et al., 1966; Kozar', 1966; Nefedov, 1964, and others).

We studied immunity indicators in 16 men who were placed under conditions of hypodynamia for 70 days (Sorokin et al., present collection).

The research carried out can be broken up for convenience into 2 parts: a) study of indices to the organism's nonspecific resistance (phagocytic activity of leucocytes, bactericidal properties and titer of complement and titer of serum properdin, lysozyme activity of saliva, bacteriostatic property of skin, etc.); b) study of indices to specific immunity to infection and the degree to which the organism is inseminated with pathogenic and saprophytic microflora. /116

The material for investigation (blood, saliva, smears, and smear impressions from the skin and mucous membranes) was taken two or three times at intervals of 7-10 days before the start of hypodynamia, thereafter every 10-20 days during hypodynamia, and 2-3 times after its termination.

In the present report, we shall set forth the results of study of only those indices that were subject to the most pronounced changes and provided a definite opportunity to follow the dynamics of the organism's resistance to infection during hypodynamia.

Among the indices to nonspecific resistance to infection that were studied, the most significant shifts were observed in leucocyte phagocytic function.

The blood for the phagocytosis studies was taken antepprandially from the finger along with the sample taken for general clinical analysis. The following indices to neutrophil function were determined (with respect to staphylococcus) after N.I. Latysheva (1955): percentage phagocytosis, phagocyte number, phagocyte index, and phagocytosis intensity (the total number of microbe cells absorbed by the neutrophils present in 1 mm^3 of blood).

All of these indicators varied during hypodynamia. However, since the absorptive function of the neutrophils is still determined on the whole by phagocytosis rate, it is most convenient to arrive at a general evaluation of the absorption phase on the basis of precisely this indicator.

It was possible to observe three basic types of disturbance to the absorptive function of blood neutrophils among our subjects, depending on their individual peculiarities. The first was manifested in a distinctly weaker ability of the blood cells to capture microorganisms during the first 2-3 weeks of hypodynamia, with a subsequent rise in this function nearly to the initial level and then another decline by the end of the 2nd month, the latter lasting through to the end of the experiment (in Ch-y, M-s, B-k, B-y, K-v, and F-v).

Shifts of the second type also involved a primary decrease of the absorption function during the first month, with a gradual rise to the initial level by the end of hypodynamia (in K-n, M. M-k, V.M-k, and L-i).

The third type of disturbance to neutrophil absorptive capacity was characterized by a decrease at the 7th to the 20th day of observation, then a brief recovery, another decrease, and, finally, a rise toward the end of the experiment (in G-y, B-v, A-v, and A-n).

It should be noted that in those cases in which the blood could be taken for examination during the first one or two days of hypodynamia (subject group III), stimulation of the absorption function could generally be observed during this period.

/117

Thus, the data obtained permit the conclusion that the absorptive capacity of the leucocytes is subject to phased changes during prolonged hypodynamia: a brief period of primary stimulation is followed immediately by a more or less protracted suppression phase and a subsequent tendency to recover. However, the latter depends on individual peculiarities and on the conditions of hypodynamia. Among subjects who engaged in a specially designed set

of physical exercises, these changes were less pronounced; however, the difference in the shifts observed in subjects of these two groups (with strict hypodynamia and with physical load) was small (Fig. 1), although statistically reliable ($P \leq 0.05$).

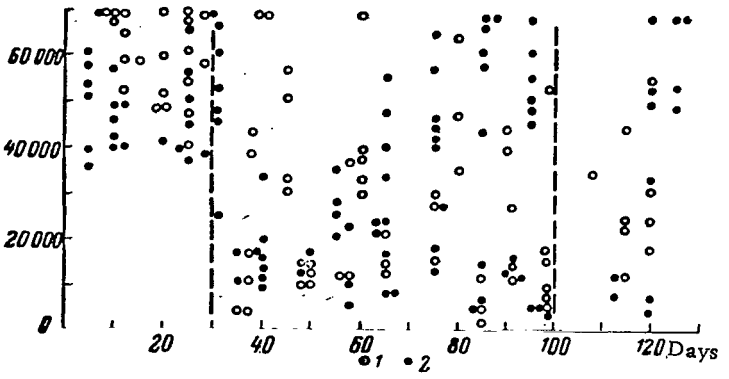

Figure 1. Absorptive Capacity of Neutrophils (Number of Staphylococci Absorbed) in Subjects who Engaged (1) or Did Not Engage (2) in Physical Exercise During Hypodynamia (Initial Condition from 0 to 30 Days, Hypodynamia from 30 to 100, Recovery from 100 to 130 Days).

The digestive function of the neutrophils is also subject to substantial variations during hypodynamia. It was determined by a technique that we developed (Ivanov, Chukhlovin, 1967) with respect to a living culture of B. coli strain 42 a.

In the initial state, the neutrophil digestive function was stable in our subjects (the digestion index, the ratio of the numbers of killed to living bacteria in 100 counted neutrophils, was in the range from 1.0 to 2.8). During the first few days of hypodynamia, a substantial rise in this index (to 5-6) was observed in half of the group III subjects (B-v, A-v., K-ya), then, in almost all subjects, a slight decrease (to 0.5-0.9) paralleling the change in absorption function, with a subsequent gradual recovery to normal. Usually, the digestive capacity of the neutrophils did not show a second sharp drop toward the end of hypodynamia, such as was observed in the case of the absorption function. /118

Consequently, the various stages of phagocytosis do not always change simultaneously and in the same direction during hypodynamia: during a given period of subjection to an unfavorable factor, suppression of one stage in phagocytosis may not be accompanied by a similar change in the other stage.

Characteristic changes can also be observed during prolonged hypodynamia in the specific immunological reactions and the obviously related indices to the microbic insemination of the organism.

In our opinion, study and prophylaxis of staphylococcus infection is one of the most pressing problems both for the clinic and for elaboration of conditions under which humans can survive

extremal disturbances.

It was the purpose of one stage in our work, in which we collaborated with S.P. Ivanova, to study, under dynamic conditions, the carrying of staphylococci, their pathogenicity and activity in the organism, and the peculiarities of mutual exchange of staphylococcus phagotypes in the subject groups.

The material for cultures to determine the presence of staphylococci was taken from the nasal mucosa with sterile cotton swabs and seeded on Petri dishes with eggyolk-salt agar. The isolated cultures were studied to determine their ability to form enzymes and were typed with a set of phages. Antienzymatic immunity to lecithinase was determined by the Chistovich method (Chistovich, 1956) and immunity to hyaluronidase by the Mogilevskiy method (Mogilevskiy, Klyuchareva, 1955).

When people come into intimate contact under conditions of partial or complete isolation, special interest attaches to the possibility of mutual exchange of staphylococci and the "taking" of the latter to their new host carriers.

The phagotypes of staphylococci taken from the nose were determined for 12 individuals in our study (in experimental series II-III and IV-V). Since the subjects were living together (in groups) even before the study was started, even though contact was less intimate than during the experiment, this may explain why certain common staphylococcus phagotypes were identified on the very first examination ("42" in one group, "80" in all subjects of the other, and "53", "54," and "71" in the majority).

Further transfer of phagotypes from one subject to another was observed during hypodynamia, with subsequent prolonged carrying (B-v received strains "71," "53," "54", and "75" from his neighbors A-v and K-ya and yielded them repeatedly; B-y was innoculated by B-k and continued to yield "Z-v" strains to the end of observation). At the same time, other staphylococcus strains found for a long time in individual subjects were not transferred to their neigobors (phagotype "6" was not transferred from A-n to /119
the others and, conversely, phagotypes "71" and "42" were not transferred to A-n from his neighbors). It may be that only certain staphylococcus phagotypes find fertile soil for reproduction and dissemination among people against the background of lowered resistance to infection (in our experiment, during hypodynamia).

In analyzing the results, our attention is drawn to the change in the number of staphylococci isolated during the observation. Thus, of 12 subjects who received repeated bacteriological examinations (experimental series II, III, IV, and V), 11 showed a substantial increase in the number of staphylococci that could be cultured from the nasal mucosa during the period of hypodynamia: while only a few colonies to tens of colonies were

registered on the dishes at the beginning of the experiment, it was generally possible to observe a solid growth of microorganisms during hypodynamia, i.e., their number had increased by tens and hundreds of times.

At the same time, distinct shifts were also observed in the pathogenicity of the isolated staphylococci. In the initial state of the subjects, most of the cultures isolated showed no signs of pathogenicity (65% of the isolated strains did not form lecithinase, 69% did not form coagulase, and 48% did not form hyaluronidase). During hypodynamia, however, almost all of the staphylococcus strains investigated tested positive for these enzymes (75% of the cultures gave positive tests for lecithinase, 76% for coagulase, and 90% for hyaluronidase).

On the other hand, in cases in which pathogenic cultures were present even at the beginning of the experiment, their pathogenicity subsequently increased substantially: the number of strains with high hyaluronidase titers (1/64-1/256 and higher) increased from 4% in the initial stage of the subjects to 21% during hypodynamia.

The manifestation of pathogenic properties by staphylococci in various states of the macroorganism can also be registered indirectly through the rate at which antienzyme antibodies are produced, provided, of course, that the subject contingents studied have adequate immunological reactivity.

A considerable increase in the titers of antilecithinase (by a factor of more than 2) and especially that of antihyaluronidase (by a factor ranging up to 8) in the blood serum of our subjects was observed during hypodynamia.

The observed changes in the quantities of antienzyme antibodies can be explained either by a stronger immunological reaction of the organism or by an increase in the activity of the staphylococci that vegetate on the skin and mucous membranes and in the tissues of humans.

The results from studies of the subjects' GIR [General Immunological Reactivity] (Ioffe, 1956) at the end of hypodynamia indicate a sharp decrease in this reactivity of the organism: of 12 subjects studied, only two showed a positive (2++) reaction. /120
There is therefore sufficient basis for the assumption that the increased titer of specific staphylococcus antibodies during hypodynamia is due basically to an increase in the pathogenic activity of the microorganisms.

Similar changes in antibody levels were also observed in this experiment with respect to other bacteria and viruses. For example, interesting data were obtained from a study of the carrying of β-hemolytic streptococci in the fauces and the levels of

anti-O-streptolysin in the blood serum[1].

The bacteriological studies produced a hemolytic streptococcus (untyped) only in subject K-s (group I) in the first phase of hypodynamia. The microbic focus was characterized by 2000 streptococci on the swab. We did not succeed in establishing transmission of the agent to other subjects of this group, since K-s was dropped from the experiment for reasons of health.

Taken alone, however, periodic bacteriological examination of the subjects to identify streptococcus carriers evidently cannot give a complete picture of the circulation of a given agent among the group. Nor does it permit inferences as to the activity of this infection in the organism during hypodynamia, although clarification of precisely this question was of greatest importance in the present study. For this reason, the bacteriological studies were supplemented by determination of anti-O-streptolysin (Rawtz and Randall, 1945) in the blood serum of the subjects at all stages of the experiment.

In the first (preexperimental) specimens of serum, anti-O-streptolysin was detected in all subjects in amounts not exceeding 63-125 AESto.[2] In sera from blood taken during hypodynamia and recovery, on the other hand, the anti-O-streptolysin level had increased to 250 AESto in individual subjects of all groups (M-s, M-k, K-ya, L-i). This increase in anti-O-streptolysin level is not beyond the normal limits, but it may nevertheless serve as an indirect indicator of some activation of streptococcal infection among the subjects during hypodynamia.

The state of antiviral immunity was studied during the experiment with respect to the agents of influenza and adenoviruses. The viruses were not isolated from the nasopharynx. It was assumed that it would be possible to establish more accurately the time of activation or the fact of infection by these agents from serological indices to strength of immunity [the CFR (Complement Fixation Reaction) and the pH neutralization reaction].

The results of the CFR with influenza antigens (types A_2 and B) were negative or weakly positive: the antibody titers did not exceed 1:10-1:20 in group II or 1:20-1:40 in group III, and they remained constant throughout the experiment. /121

The shifts toward adenovirus antigens were more conspicuous. An increase in total complement-fixing antibodies by a factor of

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[1]The author thanks A.P. Khodyrev for his aid in performance of this department of the work.

[2]The AESto is the unit of the GKI [State Quarantine Inspection] anti-O-streptolysin standard, and equals one International Unit of anti-O-streptolysin.

four or more was observed during hypodynamia in groups II and III (all six subjects) and groups IV and V (in three subjects out of six) (the final antibody titers were 1:32-1:123).

The results of the neutralization reaction that was set up in parallel with adenovirus antigens of types 3, 4, and 7 made possible more accurate classification and activity determination for these agents. It was found that an increase in neutralizing as well as complement-fixing antibodies occurred in all subjects of groups II and III (by factors of 4-16), but only to the type 3 virus, and in three subjects (B-v, L-i, F-v) in series IV and V (by a factor of 2) to virus types 3, 4, or 7. Acute respiratory ailments (acute catarrh, rhinitis) preceded the increase in the titers of the antibodies to adenoviruses according to the CFR and pH reactions in eight subjects.

When we remember that many adenoviruses may be present in the organism in a latent state (Ketiladze, 1967) and that the decrease in the organism's resistance under the influence of unfavorable conditions contributes to multiplication of viruses in the cells (Paktoris, 1967), it appears reasonable to assume that activation of adenovirus infection or perhaps introduction of a virus from the outside (type 3 virus in groups 2 and 3) occurred in our experiments, and was also followed by active dissemination of the virus among the subjects because of the lowering of resistance during hypodynamia.

Thus, the data obtained provide a basis for the general conclusion that both the nonspecific resistance to infection and the specific immunological reactivity of the organism change under the conditions of hypodynamia. This may result in intensified activity of conditionally pathogenic and saphrophytic automicroflora vegetating in the organism, and may also contribute to activation of latent infection or propagation of an agent introduced from the outside.

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FUNCTIONAL STATE OF THE CENTRAL NERVOUS SYSTEM DURING PROLONGED HYPODYNAMIA

G.D. Yefimenko

ABSTRACT: Rheoencephalography brought out consistently directed shifts in the hemodynamics of the brain in all subjects: a decrease in the blood-filling index and vascular tone index, shorter propagation times of the rheographic wave, and increased lability of the hemoregulatory nerve centers. Signs of the functional disturbances to the central nervous system that are characteristic of neurotic states were observed on the survey electroencephalograms of all subjects. There was apparently no decrease in the short-term fitness of the subjects for light mechanized labor during the 75 days of hypodynamia. Analysis of the indicators for each individual subject indicates phasing of the changes during the prolonged hypodynamia.

The results of studies of the central nervous system during comparatively short-term hypodynamia stress no pronounced changes (Graibiel et al., 1959; Akulinichev et al., 1966).

During a 30-day experiment, however, a decrease in the α-index, prevalence of the θ-wave, and the appearance of a Δ-wave was observed on the electroencephalograms of the subjects during the latter part of the experiment (Agadzhanyan et al., 1965). Discussing the results of this experiment, the authors assumed that the "long-duration factor itself" led to establishment of the nervous regulation of the organism's physiological functions on a new level and, as a consequence, development of fatigue and a decline in work performance. Opinions were offered at the XV International Congress on Aviation Medicine as to the etiology and pathogenesis of illusory disturbances that arise in spaceflight; the authors perceived the cause of the illusions in redistribution of the blood and a change in the blood filling of the blood vessels of the brain (Kosmolinskiy, Khazen, 1967). In the light of these data, it appeared advisable to study the functional stage of the central nervous system under the action of prolonged hypodynamia, one of the factors operating in spaceflight.

EXPERIMENTAL METHODS

Three methods were used. The hemodynamics of the vascular bed was studied by rheoencephalography (Jenkner, 1957, 1962), which is quite well accredited in clinical and physiological research (Kedrov, Naumenko, 1954; Orlov, 1961; Moskalenko, 1967; Gurvich, Yefimenko, 1967).

The second method consisted in study of the survey bioelectrical activity of the brain, as registered in the bipolar frontoparietal lead.

Study of the REG in parallel with the EEG does not directly answer the question as to whether a man's work performance is affected during hypodynamia. This problem was solved by determining the rate of information processing by the basic analyzers — visual, auditory, and tactile (Yegorov, 1964). /123 The study was made on apparatus designed by V.V. Rassvetayev, who kindly placed it at our disposal. Light, sound, and tactile stimuli were supplied at each step of the investigation, with selection from among four equiprobable signals of each modality. On the appearance of the signal, the subject was to press a corresponding button as quickly as possible. The signals supplied and the responses to them were registered by an oscillograph with photographic recording. The resulting oscillograms made it possible to compute the following parameters: the time of the simple motor reaction to the various stimuli, reaction time with selection from among 4 stimuli, number of errors committed in this process, amount of information processed, and rate of information processing per unit of time.

These studies were made two or three times before the experiment, once a week during hypodynamia, and at the ends of the first and third weeks after the experiment. The subject was given a different activity program in each case in order to reduce conditioning to the technique and determine the possibility of memorizing and reproducing new information under the conditions of hypodynamia.

To obtain more precise data in each investigation, the subject assimilated two programs for each analyzer. The results were then averaged.

EXPERIMENTAL RESULTS

Rheoencephalography. A rheograph with an operating frequency of 30 kHz was used. The rheoencephalograms were registered in frontomastoidal leads on a four-channel electroencephalograph (Fig. 1).

The REG indicators (Fig. 1) a, b, d, H, h, and K were used as a basis for inferences as to blood circulation in the brain, and the indices (H/K), (h/H) x 100, and d/b were computed from

them. Basically, the REG enables us to judge two qualities of the peripheral blood circulation – the intensity of the pulse oscillations of blood filling in the region under study and the state of tone of the brain vessels (Yarullin, 1967).

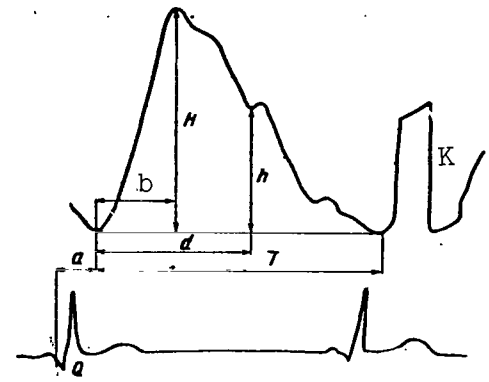

Figure 1. Diagram of REG Wave. a) Propagation time of rheographic wave; b) time of maximum blood filling of vascular bed; c) time from beginning of cycle to the appearance of notch on catacrotic part of wave; T) time of rheographic cycle; H) amplitude of REG wave; h) height of notch; K) 0.1-ohm calibrating pulse. /124

The intensity of volumetric-pulse oscillations in the vessels of the brain is determined by the ratio of the height of the REG pulse wave to the 0.1-ohm calibration signal (H/K). According to Jenkner, this quantity ranges from 0.5 to 1.0 in healthy individuals; Yarullin gives 1.0-2.7, and Eninya 1.0 to 3.0 (cited from Yarullin, 1967).

In the initial stage, the pulse blood filling index varied from 0.45 to 0.78. During the first week of the experiment, a certain rise in the index (+0.05 and +0.16) was noted in series II and IV, with a subsequent reliable decrease over the entire experiment in all subjects. Among the last four series, the largest shifts in these figures were noted in III (averaging -0.225); they were less pronounced in V (averaging -0.178), and even less so in series II and IV (-0.046 and -0.048). It is interesting that the series with the smaller shifts in this index during hypodynamia made a more rapid approach to the initial values during the recovery period. Thus, the average changes with respect to the initial data were +0.42 and +0.35 in series II during the 1st and 2nd weeks after the experiment, reached the background (-0.06) by the 3rd week in series IV, and remained significant in series III and V from the 1st through the 3rd weeks (at -0.41 and -0.25, -0.20 and -0.30, respectively).

With the general trend toward lower blood filling indices, fluctuations below and above the initial data were noted in individual subjects. Thus, in series III, the index rose substantially, especially in B-y and G-y, and less sharply in B-k, when the REG's were registered on the 2nd day of the medication cycle (5th, 8th, and 10th weeks of the experiments). On some of the registration days, the index was observed to rise above the initial values, apparently out of context with any disturbance (K-v and A-v in the 1st and 4th weeks of the experiment, B-v in the 4th and 6th weeks, A-n in the 4th week, and so forth).

On the average, the largest decrease in the blood filling index was noted at the 7th and 9th weeks of the experiment, the changes were smallest at the 1st and 8th weeks, and only at the 4th week of the experiment did it exceed the initial value.

The time interval a (Fig. 1) from the Q deflection of the EKG to the beginning of the rise of the basic REG wave has been referred to by a number of authors as the propagation time of the rheographic wave (Veyn and Ronkin, 1962; Martin et al., 1963). It is normally 0.16-0.2 sec (Veyn and Ronkin, 1962) or 0.063±0.008 sec (Naumenko, Pyatov, 1966). We assume that the variation of this index in a given subject throughout the experiment can be interpreted as a variation of the time between the beginning of the heart's systole and the arrival of blood in the vascular bed of the brain. On the average, this interval becomes reliably shorter during hypodynamia, to the greatest degree in series I (-12.92 msec), to a lesser degree in II and IV (-4.5 and -4.6 msec), and to a still lesser degree in series V and III (-2.64 and -1.00 msec, respectively). /125

Comparing these data with the variations of pulse oscillation intensity, we note that in the group in which the decrease in these oscillations is most pronounced, the changes in the interval a were minimal (series III), and, conversely, that in the series with substantial decreases in the interval a, the volumetric pulse blood filling did not suffer significantly (series II and IV).

If we concur with the authors who state that shortening of the interval a signifies an increase in the tone of the brain's blood vessels (Jenkner, 1962; Martin et al., 1963), we shall hardly be able to account for the inverse correlation noted above. There is another point of view, in which it is assumed that the interval a is an index to vascular tone on the segment from the heart or carotid artery to the zone under study (Mines, Ronkin, 1967). At the same time, if it is assumed that the variation of a is also related to cardiac activity (for example, stroke volume, pulse frequency), and with the blood supply to other peripheral basins (blood redistribution), the difference between these indicators is easily explained. In fact, an increase in stroke volume and pressure in the major vessels would result in a larger pressure drop between the center and the periphery, and this would manifest in a relative decrease of the blood flow time to the brain (shorter a) and an improved blood supply to the brain. Conversely, other conditions the same, a more "sluggish" blood flow at the center (longer a) would ultimately be detrimental to blood filling in the peripheral channel.

It appears that changes in both central and peripheral hemoregulation influence the rheographic-wave propagation time. This would also explain why a decrease in a does not always accompany improvement of blood filling. For example, following administration of a tonic preparation, the rheographic-wave propagation rate

may increase, decrease, or remain unchanged against a background of an elevated blood filling index.

Over the course of the experiment, the interval a fluctuated among the various subjects from 0.09 sec (F-v, 8th week; L-i, 3rd, 4th, 6th, and 10th weeks) to 0.17 sec (series I subjects) and even 0.21 sec (M-s, 3rd week). Beginning at the 7th week, a became substantially shorter in all of the subjects.

The objectives of our study included evaluation of the interval a under dynamic conditions over the course of hypodynamia. /126 According to data obtained by B.A. Korolev in the same experiment, the length of the ventricular tension period varies somewhat during hypodynamia (from 0.10 sec in the initial background to 0.11-0.12 sec toward the end of the experiment). If necessary, an attempt can be made to estimate the true rheographic-wave propagation time with consideration of these central-pulse variations (Tishchenko et al., this collection).

Vascular tone in the brain. A number of indices have been proposed for evaluation of the state of vascular tone. Synchronous recording of the REG and carotid sphygmogram have indicated that in some cases there are distinct differences, in both the time and the amplitude parameters, between the REG curve and the shape of the sphygmogram curve. Most often, these differences pertain to the notch on the catacrotic parts of the two curves. It may be assumed that certain peripheral hemoregulation mechanisms that modify the nature of blood circulation are set in operation, and that this is reflected in the shape of the curve for the periphery as compared with the more proximal pulse. These changes may possibly be reflected in the position and time of appearance of the notch. To evaluate the variability of vascular tone, therefore, we used the ratio of notch height to the height of the main REG wave, (h/H) x 100. The ratio of these two quantities is interpreted by Yu.N. Fedorovskiy and A.I. Kovshillo (1964) as an index to the intracranial tonic stressing of the arterial system.

The calculations made in processing the material were based on no fewer than 10-12 pulse oscillations for each trace, and $\bar{x}$ and σ were calculated. Our attention was drawn to the fact that the standard deviation varied. Beginning in the first week, the index to the variability of the process increased, reaching quite substantial values on certain days.

We perceived the physiological significance of the increase in the σ of the vascular-tone index during hypodynamia in increased lability of the nerve centers that regulate the activity of the cardiovascular system. This lability increase may also be the first step in each phase of readjustment of the cardiovascular system to a new functioning level.

At the same time, the inadequate reliability of the arithmetic mean index differences in hypodynamia and the long times required to compute the standard deviation obliged us to seek other ways to evaluate the state of brain vascular tonus.

We adopted the ratio of the time interval **d** from the start of the REG wave to the appearance of the notch on the catacrotic part of the curve to the time interval **b** of maximum blood filling (Fig. 1) as an index to intracranial vascular tonic stress. Most authors concur in the opinion that the position of the notch on the descending branch of the wave with respect to its peak characterizes the tonic state of the region investigated (Orlov, 1961; Yarullin, 1967). But in this case, other conditions the same, a decrease in the height of the notch or a shift of the notch along the catacrotic part of the curve would also change the time of its appearance reckoned from the beginning of the REG cycle. Study of the records that we obtained confirmed this hypothesis, and the scattering of the data found for each subject was only moderate. The duration of the anacrotic phase of the REG is regarded as another important index to the extensibility and elasticity of the vessel wall (Khadzhiyev, 1967; Veyn, Ronkin, 1962), although the absolute values obtained for healthy young individuals by different authors vary substantially — from 0.05 sec (Eninya, 1962) to 0.21 sec (Martin et al., 1963). According to our data, the average value for all subjects in the initial background was 0.10 sec (from 0.07, for example, in B-y and M.M-k to 0.15, as in Ch-y). The averaged data for the duration of the REG anacrotic phase for 16 subjects after 10 measurements during hypodynamia are quite unreliable: $t = 1.7$ and $0.1 < P < 0.2$. The low reliability of the maximum blood filling time variations in our studies and the substantial variations of this time according to literature data suggest that these variations must be measured along with **d**, which characterizes the state of the vessel walls during the decrease of blood flow in the vessel.

/127

The results obtained when the calculation is made by this method (Fig. 1, **d/b**) indicate a reliable decrease in the average values of the index during hypodynamia, and that this decrease becomes more pronounced beginning with the 7th week. Except for the series II subjects, two weeks of recovery do not return the index to its initial values.

Our attention is drawn to the fact that in the control series (I), the index was above the initial values for the first four weeks, reached them at the 5th and 6th weeks, and dropped sharply from the 7th week. The high initial values in series I result from K-s, whose index was 6.60 during the 1st week as against an initial value of 3.25. A sharp increase in the index during the very first week was noted in another subject, B-y. From an initial background figure of 4.28, it rose to 6.40 in the first week, but, in contrast to K-s, it decreased during the 2nd week of the experiment in B-y, and reached the initial values only during the

recovery period, while in K-s it remained high right up to the time at which the neurotic state intervened; after he terminated the experiment, the index dropped sharply (to 2.31) and had reached its initial values by the 20th day of the recovery period.

The extreme values of the index were as follows: for the initial background, from 2.00 (F-v in one of four tests) to 4.72 (B-y, in one of two tests); for the period in hypodynamia, from 2.15 (M.M-k, 3rd week) to 3.88 (same subject, 5th week, not counting K-s and B-y, who have already been discussed); for the recovery period, from 2.25 (K-n and M-s, 4th day after experiment) to 3.85 in B-k.

On the average, the deviation from the initial values was observed to be largest in series IV ($t = 10.25$); series V was next ($t = 4.7$), followed by II and III ($t = 2.51$ and 2.59); the smallest deviations occurred in series I ($t = 0.43$). /128

During recovery, series II subjects made the fastest approach to the initial data. We note that the initial indices to the degree of pulse blood filling of the intracranial vascular bed were reached and exceeded in the 1st and 2nd weeks of the recovery phase only by subjects of this same group.

The electroencephalograms were registered synchronously with the REG on a 4-channel electroencephalograph. The EEG's were processed by the generally accepted methods (Kozhevnikov, Meshcherskiy, 1963; Kratin et al., 1963).

Various EEG deviations were noted in the initial background for 5 out of 16 subjects (one in each series). For the group of subjects characterized by a distinct, regular α-rhythm in the initial period (11 subjects), dysrhythmia and the appearance of slow waves must be regarded as the most typical changes during hypodynamia. Beginning in the 2nd-3rd week of confinement to bed, the α-rhythm became unstable in amplitude and frequency, with the broadening of the α-rhythm frequency spectrum taking place, as a rule, in the direction of slower oscillations. With manifest dysrhythmia, θ- (in 8 subjects out of 11) and β-potentials appeared. On some days, the EEG traces were diffusely lowered or flat, and the α-rhythm lost modulation or vanished altogether. Sharp waves and peaks were observed on the EEG's of some of the subjects.

In the group of five subjects with modified background EEG's, the signs of functional disturbances were better-defined and more frequent. Pronounced dysrhythmia was noted in three subjects out of the five, slow θ-waves in four, Δ-waves in two, and α-rhythm disappearance, sharp waves, and frequent potentials in one case each.

As a rule, hyperventilation gave rise to the appearance of an α-rhythm on the EEG if it was absent at rest, and to the disappearance or a substantial decrease in the number of slow waves.

Changes were noted in the response to opening and closing of the eyes — specifically, exaltation of the α-rhythm instead of suppression when the eyes were opened or, on the other hand, absence of α-activity when they were closed.

Recovery of the α-rhythm at rest and even an approach of the EEG to its initial form could be observed on certain days during the experiment (K-n in the 10th week; G-y in the 5th week; M. M-k in the 10th week), but "deterioration" of the EEG — the appearance of a set of indicators characteristic for individuals with neurotic states — must be regarded as the general dynamic trend of the EEG during hypodynamia. It is in just this type of patient that we encounter instability of the brain rhythms on repeated examinations, moderate dysrhythmia with frequent low-amplitude slow (θ) oscillations, an even, high-amplitude α-rhythm, and flat EEG's (Peymer, 1966). /129

The background EEG had been restored in some of the subjects (Ch-y, G-y, A-v, A-n) by the end of the 2nd week after the experiment.

Investigation of work performance. Analysis of the results permits the following general conclusions: the speed of the simple motor reaction decreases during hypodynamia, while the speed of the reaction with selection from among four signals increases; the number of information-processing errors decreased for the auditory analyzer and remained practically unchanged for the visual and tactile analyzers (on the average, +0.08 and -0.07 errors for every 20 signals). The amount of information processed for 1 signal (I) increased, and the rate of information processing (C) also increased, by an average of 0.57 bit/sec.

During the recovery period, the speed of the selection reaction increases still further, with times more than 0.1 sec shorter than the initial times; the number of errors drops off sharply and the rate of information processing rises. At the end of the 1st week of recovery, the time of the simple motor reaction increases above the initial level, but it reaches normal at the end of the 3rd week or even drops slightly below the values of the initial indices for the visual analyzer.

The question arises as to the reason for the increased rate of information processing during hypodynamia. On the basis of the formula by which it is calculated, $I/(t_b - t_0)$, an increase in C could occur either on an increase in the amount of processed information (I) or on a decrease in the difference between the time of the selection reaction and the time of the simple motor reaction. Both processes were observed.

Comparing the results for each of the analyzers, we may conclude that the auditory and, to a lesser degree, the tactile analyzer are more stable under the conditions of the experiment. When information is processed by the auditory analyzer, we note a substantial decrease in the number of errors, the simple motor reaction time increases slightly, and the time of the selection reaction is shortened by a larger amount, with the result that the speed of information processing increases. When the tactile analyzer is investigated, on the other hand, we observe an increase in the simple motor reaction time, an insignificant shortening of the selection reaction time, and a small increase in information-processing speed (on the average, +0.43 bit/sec), although the number of errors remains practically at the initial level.

On comparing the averaged dynamic data for the three analyzers, we note a certain "improvement" in all parameters beginning at the 6th-7th weeks of hypodynamia, except for the simple motor reaction time, which remains at the level of the initial figures to the 7th week, after which it shows a distinct increase.

DISCUSSION OF RESULTS /130

In analyzing the data obtained, it is necessary to take into consideration certain peculiarities in the background data for the subjects. Thus, according to our figures, EEG's with manifestations of a modified functional state were observed in 31% of the subjects. The same applies to the background REG's. For example, in subject B-v, the intracranial vascular bed pulse-filling index reached 0.5 in the first registration, had dropped to 0.2 after three days, and reached 1.0 after another 7 days; only then did it stabilize. Similar variations were observed in F-v, K-ya, and A-v.

A background decrease in the vascular-tone index (d/b) was observed in L-i (from 4.57 to 3.00), V. M-k (3.34-2.82), and M. M-k (4.00-3.75). The time of the anacrotic part of the REG curve shortened in F-v from 0.14 to 0.08 sec, in A-v from 0.13 to 0.08 sec, in A-n from 0.11 to 0.08 sec, and in K-ya from 0.12 to 0.07 sec.

These changes over the 20 days preceding the experiment gave reason to assume that the first few weeks of hypodynamia can be regarded not only as the onset of a new factor, but also as a period of recovery from the disturbances that preceded them. We regard the two centrifuge experiments, which were carried to the point at which functional disorders appeared, as having been the most important among these disturbances.

If the above hypothesis is correct, certain practical conclusions with a bearing on proper evaluation of the results suggest themselves: a) the undulating variations of the individual indices

to the functional state of the nervous system during hypodynamia may be a result of interaction of two processes – the influence of the hypokinetic factor on the one hand and, on the other, that of the recovery process of the functions after the overloads that had been sustained; b) in comparing the data obtained with similar studies, it is necessary to consider the nature and degree of the preliminary disturbances experienced by the subjects.

It is necessary to bear the following in mind in analyzing the differences betwenn the subject groups. The blood-filling and vascular-tone indices calculated from the REG's do not provide a sufficient basis for conclusions as to quantitative changes in the hemodynamics of the brain. Only the directivity of the process and the degree of this directivity in relative units can be judged from these indices, and these units must be evaluated cautiously as an index to the degree of compensation or decompensation of peripheral blood circulation. This must be given particular emphasis for the blood circulation of the brain, which has rather powerful protective mechanisms against disturbance by unfavorable factors. Analyzing the REG shifts in the above light, for example, in series IV-V, we do not yet have adequate basis for concluding poor tolerance of the hypodynamic factor. These substantial shifts might, to the contrary, indicate /131
an increased lability that reflects a phase of adaptation during transition to a new functional level.

The observed increase in the speed of information processing is easily explained by familiarization of the subjects with the technique. However, the element of familiarization from test to test is inprobable, since we did not observe any decrease in the number of errors in information processing by two out of three analyzers. The amount of information processed and the speed of its processing increased because of an increase in the difference between the selection-reaction time and the progressively increasing time of the simple motor reaction, i.e., because the time actually spent by the subject in shaping the response became shorter. But even if we assume the possibility of training in hypodynamia, this would itself indicate active functioning of the central nervous system and its highest division, the brain cortex.

On the basis of the above, we may conclude that during prolonged – up to 70 days – hypodynamia, the CNS supports the performance of a man engaged in light mechanized work with an activity interval of 20-25 min (the time required for each test), with no significant qualitative or quantitative loss of productivity.

All parameters characterizing the functional state of the central nervous system during prolonged hypodynamia reflect fluctuations of this state, with the largest changes occurring in weeks 1-2, 4-5, and 7-10 of the experiment. The differences between these times are apparently determined by the individual peculiarities of the subjects and the prophylactic measures used.

CONCLUSIONS

1. The study methods used were found to be quite informative as applied to the conditions of the experiment, and make it possible to characterize the functional state of the central nervous system.

2. Rheoencephalography made it possible to bring out unidirectional shifts in the hemodynamics of the brain during hypodynamia that were, on the average, characteristic for all subjects: a decrease in the vascular filling and tone indices, shorter propagation times of the rheographic wave, and increased lability of the hemoregulatory nerve centers.

3. The survey electroencephalograms of all subjects show signs of functional disturbances to the central nervous system that are characteristic for neurotic states.

4. The short-term fitness of the subjects to perform easy mechanized work showed no apparent decrease during the 70 days of hypodynamia.

5. Analysis of the indices for each individual subject indicates phasing of the changes during the prolonged hypodynamia. /132

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CHANGES IN THE FUNCTIONS OF THE NERVOUS AND MUSCULAR SYSTEMS UNDER THE INFLUENCE OF PROLONGED HYPODYNAMIA

/133

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ABSTRACT: Nervous-system changes were studied in 16 healthy young males under the influence of prolonged (up to 70 days) hypodynamia. Definite staging of the changes was discerned. The initial stage was characterized by early adaptive reactions, and the intermediate stage by atrophy of muscules, especially those of the lower legs. The advent of the third stage (after 20 days of hypodynamia) was marked by disturbances to higher nervous activity: disturbed sleep, emotional disturbances, and other asthenic symptoms. An acute neurotic state in which there was an importunate and uncontrollable desire to move developed in one of the subjects on the 20th day, and he was obliged to leave the experiment. Thereafter, with the asthenic state as a background, oral-automatism phenomena and signs of "pyramidal insufficiency" made their appearance among the remaining subjects. The latter were manifested in increased tendon and periosteal reflexes in the right extremities, loss of strength in these extremities, decrease or loss of the abdominal and plantar reflexes, again on the right side, smoothing of the right nasolabial fold, and deviation of the tongue to the right. This set of signs indicated the development of interhemispheric asymmetry with hypodynamia, with functional insufficiency of the dominant hemisphere. This syndrome was noted in 14 out of 16 subjects. A gradual recovery of nervous-system functions was observed after reactivation. The authors attach great importance to systematic exercising of the standing and supporting mechanisms, preferential physical exertion on the left extremities, and autogenous conditioning in its psychotonic modification as prophylactic measures against these disturbances.

A disproportionately small amount of effort has been applied to study of nervous-system activity in the development of the prolonged-hypodynamia problem. Facts with a bearing on a few of its functions have been acquired by representatives of space medicine, physiologists, therapists, psychophysiologists, and psychologists, and less often by psychiatrists. In the literature available to us, we have been unable to find information on the nature and

dynamics of the neurological manifestations of prolonged hypodynamia with a clinical method of nervous-system study at their base. Published papers have been devoted chiefly to study of individual psychological or physiological parameters of nervous activity. The present study sets forth the results of a systematic investigation of nervous- and muscular-system functions in healthy individuals who were strictly confined to bed for 70 days.

NATURE AND DYNAMICS OF NEUROLOGICAL DISORDERS DURING HYPODYNAMIA (EXPERIMENTAL SERIES I)

On the 2nd and 3rd days of hypodynamia, all four of the subjects under observation complained of dull pains in the small of the back and lower abdomen, and these persisted through to the 7th day. A feeling of weakness appeared at the 4th day of hypodynamia and lasted until the 8th or 9th day. Over the first 20 days of hypodynamia, the subjects remained in a good mood and slept normally. In the latter half of the 20th day, the subjective state of K-s deteriorated abruptly. Turning his head or even his eyeballs made him feel dizzy. He developed a variety of dull headaches and a feeling of heat and heaviness in his head. His thoughts became "confused and unconnected... It is impossible to concentrate on anything." An importunate desire to move arose and was suppressed with difficulty. He could not sleep for any length of time. He slept only 3-4 hours that night. On the 21st day of hypodynamia, all of these sensations became much stronger. He again slept poorly that night. On the morning of the 22nd day, he broke into tears "over nothing," and could not overcome his desire to move or control himself." He began to try to get out of bed and move in any way possible. His appearance was confused, excited, and frightened, and his eyes were watery. He responded to questions with monosyllables in a dull, quiet voice. There was pronounced general hyperhidrosis and tremor of the fingers. The decision was made to drop him from the experiment, with a gradual /134
return to normal motor activity. Mental and physical exertion continued to tire him quickly over the next 10 days. Reading fatigued him. He complained of weakness in his arms and legs, general debility and physical fatigue ("I can't even breathe as deeply as I could before"). The sensation of heaviness and an unpleasant sensation in the region of the forehead and the bridge of the nose persisted. He was unusually thirsty for a week after beginning to get out of bed (he drank 600 to 800 ml of water per day in addition to the standard food ration). Diuresis was low (200-300 ml per day). His sleep remained disturbed: sleep came slowly and was brief and superficial with frequent awakenings.

The other subjects also showed signs of a certain asthenization on days 30-36 of hypodynamia. Sleep disturbances were first to appear: sleep came slowly (from 30 minutes to 3 hours) and was fitful. The subjects reported that their dreams had become unpleasant: falling from a great height, sinking to a great depth. Objectively, the sleep disturbances were registered quite

distinctly, both aktographically and aktometrically: sleep came slowly, the periods of deep sleep became shorter and less frequent, and prematinal motor activity appeared earlier. Emotional disturbances appeared almost simultaneously with the disturbances to sleep: acute, sensitized awareness of surrounding events and increased amplitude of the emotional reactions. Frequent changes of mood for no reason whatever during the course of the day were highly characteristic: for no apparent reason, a cheerful mood would be supplanted by moderate depression and vice versa. At the end of the second month of hypodynamia, reading fatigued the subjects more quickly, and their heads "felt heavy." All of these disturbances showed a tendency to increase during the final period of the tests. Thus, on the 69th day of hypodynamia, subject Ch-y became considerably more depressed, slept fitfully, and felt apprehensive regarding an impending orthostatic test.

Among other disturbances, we should note the appearance of hyperhidrosis and the palmomental reflex in all subjects on the 22nd day of hypodynamia. By the 31st day, these signs had become more distinct, bordering on general hyporeflexia. Toward the end of hypodynamia, the proboscis reflex was also frequently observed.

TABLE 1. DYNAMICS OF VARIATIONS IN GIRTH OF EXTREMITIES (in cm) DURING PROLONGED HYPODYNAMIA

Data	Initial date	Days into investigation					Deficit
		11	22	36	44	64	
Upper arm	29	29	29	29	29	29	0
Thigh	51	51	50	50	49	49	2
Lower leg	37	35	35	35	34	33	4

The decrease in the strength and tone of the muscles and muscular atrophy were most pronounced in the muscles of the legs, i.e., these changes developed sooner in those groups of muscles subjected to smaller physical loads. Let us examine certain illustrative data. In subject Ch-y, examination with a Sirmen myotonometer showed no convincing changes in muscle tone in the upper extremities throughout the entire time in hypodynamia. At the same time, a decrease in both rest tone and contraction by /135
10 myotones was observed in the quadriceps femoris toward the end of hypodynamia. Similar changes were also noted in the other three subjects. The same type of relationship was observed in the development of muscular atrophy. Table 1 indicates the dynamics of the girth changes of the extremities in subject M-s.

With an electromyograph, the biocurrents of the limb muscles were studied using paired rectangular skin electrodes spaced at 2-cm intervals. These tests were made at rest and at slight and

maximum exertion, in some cases with simultaneous dynamometry. As the end of hypodynamia approached, the amplitudes of the muscle biocurrents had decreased sharply at maximum muscular effort. This decrease was found to be substantial in the proximal muscle groups and especially in the muscles of the legs, and the amplitude often dropped to one-fourth of its initial level. No changes could be detected in oscillation frequency.

The electrical excitability of the muscles by galvanic and faradic currents had increased in all subjects by the 13th day of hypodynamia. On the 22nd day, muscular electrical excitability dropped markedly, and thereafter it fluctuated only slightly through to the end of the period in hypodynamia. There were no qualitative changes in electrical excitability.

Study of two-dimensional sensitivity, motor reproduction, and kinesthesiometry of the extremities brought out no marked deviations from normal. Study of pain thresholds with A.I. Vozhzhova's algesimeter showed a certain increase beginning at the 22nd day of hypodynamia.

Regular changes in skin temperature were observed in electric-thermometer studies: in the distal regions of the extremities, it came to equal and even exceed the proximal skin temperature. Table 2 indicates the dynamics of skin-temperature variation in subject M-s.

TABLE 2. DYNAMICS OF SKIN-TEMPERATURE VARIATIONS DURING PROLONGED HYPODYNAMIA /136

Data	Days into investigation				
	Initial data	11	22	36	64
Neck	33,4	33,3	34,4	35,0	34,0
Upper arm	33,2	31,0	33,2	34,0	33,2
Dorsum of hand	30,3	31,0	36,8	34,2	33,2

Quite probably, these variations of skin temperature can be related to regional hemodynamic disturbances. In orthostatic tests after hypodynamia, dizziness, nausea, shivering, cyanosis of the face, pains in the forehead, fine horizontal nystagmus, pronounced phenomena of oral automatism, the illusion of having been turned upside down, and general hyperhidrosis were noted in all subjects. One of them (M-s) went into fine generalized clonic spasms and briefly lost consciousness at the 5th minute of the orthostatic test. Neurological examination of two subjects 40 minutes after spinning on a centrifuge showed distinct tremor of the tongue, eyelids, and the fingers of the extended hand, oral-automatism reflexes, revival of the tendon and periosteal reflexes

and loss of abdominal reflexes.

During the recovery phase (motor reactivation and functional normalization), general weakness and easy tiring were noted for two more weeks, along with orthostatic vertigo, the feeling of heaviness in the head, instability in the Romberg position, and aches and pains in the tarsal bones, talocrural joints, and the muscles of the shank. The weakness and pains in the legs made it difficult to walk. It was especially difficult to climb a laddar, in which the subjects usually had to be helped.

Analysis of the results from the clinical-neurological observations and the other methods indicates that the changes that take place during prolonged hypodynamia do so in certain stages. The first stage, which lasts about 10 days, is characterized by early adaptive reactions. For example, slackening of the pulse by 4-5 beats (by comparison with the initial data) is noted, dull pains arise in the small of the back and lower abdomen, and there is a general feeling of weakness. In the second (intermediate) stage, which also lasts about 10 days, these unpleasant sensations disappear. A general feeling of well-being is preserved, the mood is good, and sleep is normal. At the same time, the electrical /137
excitability of the muscles rises, certain signs of demineralization are noted (an increase in blood serum calcium content), and incipient atrophy of the leg muscles appears. Another hemodynamic readjustment occurs. The pulse quickens by 10-20 beats over the initial figures. Arterial pressure is unstable and shows a tendency to drop. Obviously as a result of regional hemodynamic disturbances, skin temperature undergoes regular variations: it increases on the distal divisions of the arms and legs and the proximal and distal readings tend to equalize. While the disturbances registered in the second stage are basically peripheral, the third stage (after the 20th day of hypodynamia) is marked by the appearance of disturbances to higher nervous activity, oral-automatism reflexes, and other cerebral disturbances. The peripheral shifts noted earlier are aggravated.

The above conceptions as to the stagewise development of nervous-system disturbances during hypodynamia were confirmed by the results of the following clinical experiments.

RESULTS OF STUDIES IN SERIES II AND III CLINICAL EXPERIMENTS

The subjects of the first group (series II) were effectively in the state of prolonged hypodynamia. As for the second group (series III), the set of physical exercises in which the subjects engaged essentially precluded speaking of hypodynamia. Their sleep and higher nervous activity were also regulated to a considerable degree by autogenous training. However, in spite of the physical exercises, the conditions of the experiment also led to considerable impoverishment of postural sensomotor reactions.

During the first stage, the individuals who received mixed medication for 3-4 days complained of pains in the muscles of the spine, the small of the back, and the lower abdomen. There were no such complaints among the group II subjects. Both groups tolerated the intermediate stage about equally well. Thus, the speed and extent of lower-leg muscle atrophy were almost the same; nor were there any impressive differences in the dynamics of other indicators.

Substantial differences were observed during the third stage. While the basic neurological symptomatics (emotional changes, disturbed sleep, nystagmoid spasms of the orbits, oral-automatism reflexes) appeared toward the beginning of the third stage (after 20 days of hypodynamia) in group I, it appeared 10-12 days later in the second group of subjects and was milder. For example, sleep disturbances and gross oral-automatism reflexes were not observed in the second group. The disturbances to higher nervous /138
activity in the group I subjects had a tendency to progress. They were especially strongly in evidence on the days on which the medication was received. After the preparation had been taken, there was sometimes pronounced euphoria with motor restlessness, disturbed sleep, and subsequently developing depression.

A new and highly interesting fact that still requires pathophysiological interpretation was the asymmetry of the tendon, periosteal, and skin reflexes that appeared in the subjects during the third stage of hypodynamia. At the beginning of the third stage, this took the form of a slight predominance of the tendon and periosteal reflexes on the right; then the abdominal reflexes declined on the same side, the tongue would sometimes deviate to the right, and the right nasolabial fold would smooth out. In other words, the set of symptoms that neuropathologists refer to as the pyramidal-insufficiency syndrome had made its appearance. Curiously, the "pyramidal insufficiency" appeared only on the right side in those cases in which it was registered. This syndrome was most conspicuous in group I subjects. We noted the first signs of it in subjects B-k and B-y on the 20th day, and in G-y on the 32nd day of hypodynamia. Elements of this syndrome could also be noted in group II subjects, but they appeared much later and were not as pronounced. With increasing time in hypodynamia, these disturbances progressed and came to full flower at the end of the experiment, especially after orthostatic tests and subjection to transverse g-forces on the centrifuge. The nature and dynamics of the neurological disorders that resulted from prolonged hypodynamia are reflected in Tables 3 and 4.

As we see from Table 3, the signs of the dextral "pyramidal-insufficiency" syndrome that appeared on the 20th day of hypodynamia increased progressively with the passage of time along with the appearance of other symptoms and exacerbation of the oral-automatism phenomena. Our attention is drawn to the fact that the "pyramidal insufficiency" is indicated not only by reflex

TABLE 3. NEUROLOGICAL DISORDERS DURING PROLONGED HYPODYNAMIA (B-k, /139 GROUP I)

Day	General Subjective State and Sleep	Neurological Status	Dynamometry of Hand (kg)		Arm (Right, Left)	Lower Leg (Right, Left)
			dex	sin		
Initial data	Normal	Normal	53	47	29-29	35-35
8	Muscle pains	Normal	48	47	29-29	34-34
20	Irritability, time to fall asleep had increased to 1.5 h	Mild Marinesco's symptom and proboscis reflex, slight predominance of right arm and leg reflexes	48	45	28-28	33-33
32	Irritability, time to fall asleep up to 2 h	Same. Nystagmoid spasms. Tongue deviated to right	48	47	27-26	32-32
43	Same data	Same symptomatics. Proboscis reflex stronger and predominant on right	48	46	27-26	31.5-31
53	Same data	Same data. Slight decrease in right abdominal reflexes	48	47	27-26	31-30.5
69	Same data	Exacerbation of above symptomatics	44	47	27-26	31-30.5
Decrease compared to initial data			9	0	2-3	4-4.5

disturbances, but also by a marked loss of strength on the homolateral side. While the strength of the left hand remained unchanged, according to the dynamometer, on the 69th day of hypodynamia, it had fallen by 9 kg in the right hand. Neurological disturbances of about the same type were also noted in the other subjects of group I. One of the observations (subject M-k, Table 4) can serve as an example of good tolerance of prolonged hypodynamia.

TABLE 4. NEUROLOGICAL DISORDERS IN PROLONGED HYPODYNAMIA (M-k, GROUP II) /140

Day of Hypodynamia	Neurological Status	Dynamometry of Hand (kg)		Girth	
		dex	sin	Arm	Lower Leg
Initial data	Normal	48	42	29-28	37-37
8	Normal	48	45	29-28	36-36
20	Mild nystagmoid spasms	52	42	29-28	34-35
32	Same data. Marinesco's symptom	48	43	29-29	34-34.5
43	Pronounced nystagmoid spasms and Marinesco's symptom	48	41	28-28	33.5-33.5
53	Pronounced Marinesco's symptom; bilateral nystagmus	49	42	29-28	33-33
69	Same data	49	42	29-28	31-31

*During this period, the subjective state of being and sleep remained normal.

All other group II subjects continued to feel good throughout the entire period of hypodynamia. On the 32nd day, M-k began to show nystagmoid spasms on looking to the right, and his mood fluctuated periodically (irritability would be supplanted by apathy two or three times a day). Slight predominance of the knee-jerk reflex on the right was noted at the 53rd and 69th days. Mild nystagmoid spasms were noted in K-v on the 20th day, dextral nystagmus and Marinesco's symptom on the 43rd day, and a dextral decrease in the abdominal reflexes and predominance of the right knee-jerk reflex on the 53rd day. Smoothing of the right naso-labial fold appeared on the 69th day.

Orthostatic tests and a test for tolerance of transverse load factors, which were carried out on the 69th and 70th days of hypodynamia, produced distinctly different results in groups I and II. The group I subjects reported dizziness and headaches immediately after centrifuging or orthostatic testing. The neurological symptomatics became quite pronounced among subjects of this group soon after these loads were imposed. Nystagmoid spasms or nystagmus (usually on the right), intention tremor, outside misses in the finger-to-nose test, and gross oral-automatism reflexes were noted (in one of the subjects, the proboscis reflex was so demonstrative at this time as to approach the proportions of a "magnetic" reaction). A distinct "dextral pyramidal

insufficiency" symptom was discerned (deviation of the tongue to the right, smoothing of the right nasolabial fold, absence or decrease of abdominal reflexes, pathological exaggeration of tendon and periosteal reflexes on the right arm and leg and, in one case, the appearance of Bechterew's symptom on the right foot). These changes persisted for several days, gradually becoming less distinct, and they became milder during recovery, disappearing, on the average, at the 7th to 10th day after motor reactivation.

The group II subjects showed the best tolerance to the orthostatic test and transverse load factors. Following application of these loads, they reported no unpleasant subjective sensations, and objective examination showed only nystagmoid spasms and a moderate intention tremor in the finger-to-nose test. During the /141
recovery phase, which was shorter than for the group I subjects, one subject showed no neurological symptomatics, the second was found to have only slight predominance of the dextral knee-jerk reflex, and the third had a mild "dextral pyramidal insufficiency" syndrome (smoothness of the right nasolabial fold, diminished abdominal reflexes, and exaggeration of the knee-jerk reflex on the right side).

Comparison of orthostatic-test and transverse-g tolerance as manifested in the group I and II subjects with tolerance in subjects for whom no prophylactic measures had been taken indicates the possibility, in principle, of mitigating the undesirable effects of hypodynamia on the nervous system. This refers in part to the use of medications, but to a greater degree to physical exercises.

RESULTS OF SERIES IV AND V EXPERIMENTS

The nervous-system changes observed in subjects of these two series showed the same distinct staging as in the previous clinical experiments. Atrophy of the muscles of the lower leg was particularly rapid during the first two stages. The rate of the atrophic process then became somewhat slower. It proceeded at different rates in the right and left legs. The muscles of the left lower leg atrophied to a greater degree. Atrophy was less pronounced among subjects who exercised on the treadmill. For those who exercised on the bicycle ergometer, the girth of the lower leg decreased during hypodynamia by averages of 2.7 cm (right leg) and 3 cm (left leg). For the treadmill users, the corresponding figures were 2.3 and 2.8 cm. There is an apparent paradox in the fact that despite the lighter physical loads on the muscles of the arms, they not only showed no atrophy, but even increased in girth during the time in hypodynamia (by an average of 0.5 cm).

A study with Sirmen apparatus showed a decrease in muscle tone, which was most rapid over the first two stages. During the third stage of hypodynamia, the loss of tone was not as steep. By

the end of the experiment, the tone deficit averaged 12 myotones. As in the previous cases, the leg muscles were found to be noticeably weakened.

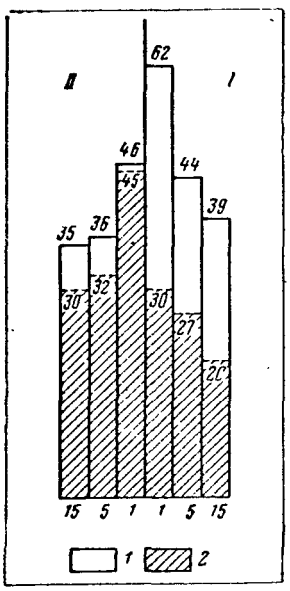

Figure 1. Strength and Fatiguing of Muscles of Right (I) and Left (II) Hands of Subject K-s (Series I).

For the arm muscles, it was not the absolute dynamometer readings that were most convincing, but instead the relative strength deficit in comparison of the right and left sides. The data in Fig. 1 (1) indicate that the subject is right-handed (the strength of the right hand was 62 kg in a single measurement, 44 after 5 compressions of the dynamometer, and 39 after 15 compressions. The results for the left hand are lower, at 46, 36, and 35 kg, respectively). On the 22nd day of hypodynamia (2), an acute neurotic state had developed, and the experiment was broken off. By this time, the sharp drop in strength in the right hand (30, 27, and 20 kg), together with the insignificant decrease in the left hand (45, 32, and 30 kg) convincingly illustrates the presence of the hemispherical-asymmetry phenomenon with functional inadequacy of the dominant (left) hemisphere. Thus, the right arm was also found to be the weaker one under the influence of hypodynamia in the preceding clinical experiments. In the present clinical experiment, the same rule was observed, and could be traced more clearly immediately after orthostatic tests and transverse load factors. The strength deficit averaged 7.5 kg for the right arm and 4.9 kg for the left. The relatively larger decrease in the right arm by comparison with the left had as a consequence in three subjects that the strengths of the two arms became equal, while one subject showed preferential weakness of the right arm.

/142

Again in this clinical experiment, the third stage of hypodynamia was marked quite clearly, primarily by disturbances to higher nervous activity. The early manifestations were disturbances to sleep and in the emotional sphere. Although they did not develop into a distinctly neurotic state, they nevertheless substantially lowered ability to do mental work and affected the general subjective state of the subjects and their attitudes toward events taking place around them. Observations made on A-n may be of interest as an illustration on the psychological level. On the 10th day, along with a slight headache and the feeling of stuffiness in the head, he reported that his mood had deteriorated. He began to experience difficulty in ordering his thoughts and

concentrating his attention. Efforts of the will did not help. "I want to do something, but when I pick up a book or a letter I get nothing out of it. I cannot concentrate, I get bored quickly and lose interest." Later, these changes and sleep disturbances (difficulty in getting to sleep, nightmares, waking up early) were compounded by elements of disturbances of an apathetic-abulic nature. "I have become completely indifferent to a lot of things and have lost interest; somehow everything has withered. I have no particular desire to do anything." Apathy would then alternate with periods in which minor occurrences would cause irritation, usually associated with a throbbing sensation /143 in the head and sensations of heaviness in the forehead and temples.

Roughly similar disturbances to higher nervous activity were noted in the other subjects.

The first convincing changes in reflex activity also appeared during the third stage of hypodynamia. Rapid exhaustion of abdominal reflexes was observed in B-v on the 20th day of hypodynamia. On the 30th day, the dextral carporadial, knee-jerk, and Achilles-tendon reflexes showed a slight predominance. On the 46th day, these changes had become coarser and muscular strength had diminished, to the greatest degree in the right arm (before hypodynamia, the dynamometer had indicated the strength of the right hand as 62 kg, and that of the left hand as 57 kg; the corresponding figures on the 46th day were 50 and 51 kg). In addition, disappearance of the abdominal reflexes was noted on the 56th-60th days. For F-v, general hyporeflexia had developed on the 20th day, and the abdominal reflexes had vanished; on the 46th day, the nasolabial fold had been smoothed and the knee-jerk and Achilles reflexes were stronger on the right side and muscular strength had diminished (more sharply on the right); anisocoria, a sinistral Marinesco's symptom, and predominance of the dextral arm reflexes made their appearance.

Disturbances of similar nature and dynamics were also recorded for all other subjects. Since the "dextral pyramidal insufficiency syndrome" appeared in this clinical experiment, as it had in the previous ones, it appeared important to clarify the mechanism by which it develops. If it is assumed that a latent, hitherto compensated nervous-activity defect (traces of earlier inflammatory or traumatic injury to the brain among the subjects) "becomes manifest" under the influence of hypodynamia, it would appear difficult to account for the fact that it always localizes on one side. In this context, we made especially thorough neurological studies of the subjects before they entered hypodynamia, attempting to bring out the most minute signs of traces of illnesses sustained previously or asymmetries of innervation. Of six subjects, three were given absolutely clean neurological bills of health. The other three were also classified as neurologically healthy, but certain modifications were detected in

their neurological status. Thus, subject K-ya showed a slight predominance of the left knee-jerk reflex, L-i a slight anisocoria and slight smoothing of the right nasolabial fold, and A-n a slight insufficiency of convergence on the right with a slight dilation of the pupil on the same side and a certain enhancement of the knee-jerk and Achilles reflexes on the left.

Figure 2. Exacerbation of Central Paresis of Facial Musculature on the Right Side under the Influence of Prolonged Hypodynamia. Subject L-i (Experimental Series V).

When subject L-i began to show symptoms indicating functional insufficiency of the left hemisphere (including, as the photograph shows, signs of dextral paresis of the facial musculature of the central type, which was aggravated by hypodynamia), this might have been explained by decompensation of a defect that had existed previously under the influence of the prolonged hypodynamia. However, in subjects K-ya and A-n, in which we might suppose an initial deficiency of the right hemisphere and expect it to become worse during hypodynamia, the right-hemisphere symptomatics subsequently abated and signs indicating functional insufficiency this time of the left hemisphere made their appearance. These facts once again confirm the correctness of our conceptions of mechanisms by which interhemispheric asymmetry with functional insuffuciency of the dominant hemisphere develops. The "dextral pyramidal insufficiency" syndrome developed in all subjects at various times (from the 20th to the 46th day of hypodynamia). Functional insufficiency of the dominant hemisphere was expressed not only in the reflex changes, but also by a sharper decrease in the strength of the right hand as compared with the left (according to dynamometer data acquired before and at the end of hypodynamia). The muscular-strength deficit that develops under the influence of hypodynamia reached values 3 kg (in three subjects) and 4 kg (in two subjects) higher for the right hand than for the left hand. In only one subject (A-n) was this deficit larger for the left hand (by 2 kg) than for the right at the end of hypodynamia. When this observation was made in the neurological examination before hypodynamia, a slight dilation of the right pupil, slight dextral convergence insufficiency, and predominance of the left knee-jerk and Achilles reflexes were established.

/144

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These signs might indicate an initial functional insufficiency of the right hemisphere. Over the first 20 days, these symptoms persisted, but then the right nasolabial fold smoothed out and the right-side reflexes came to predominate slightly (on the 20th day); later, slight deviation of the tongue to the right, together with aggravation of the right-hemisphere symptomatics were added to this picture (30th, 46th, and 46th days). Thus, the initial insufficiency of the right hemisphere, in combination with convincing signs of detrimental effects of hypodynamia on the dominant left hemisphere, were brought out more clearly in this observation under the influence of prolonged hypodynamia. It is obvious that hypodynamia may indeed have a "developing" effect on a latent defect that has been compensated to one degree or another. However, even decompensation of this right-hemisphere defect could not interfere with the development of the left-hemispheric disturbances, which are in our opinion typical of prolonged hypodynamia.

In the neurological examination, all subjects felt good 1 hour after centrifuging. Objectively, however, a marked increase in the manifestation of the "dextral pyramidal insufficiency" syndrome was noted.

In the orthostatic tests, only one of the subjects (F-v at the 11th minute) went into a state of near collapse, with vertigo, nausea, an overheated feeling, and general hyperhidrosis. The other five reported no unpleasant sensations. A neurological examination made an hour after the orthostatic tests showed increased signs of left-hemispheric disturbances. In addition, distinct coordination disorders were noted in five subjects (the exception was A-v), taking the form of an intention tremor in the finger-to-nose test, which became stronger in the vertical position and was asymmetrical (stronger on the left). In the attempt to walk with the eyes closed and in the complicated Romberg position, the subjects leaned to the left or had a tendency to fall backward and to the left.

During the recovery period (motor reactivation), the subjects complained for 12-14 days of pains in the ankle joints, feet, and lower legs; they showed occasional and gradually subsiding neurological symptoms (anisocoria, nystagmoid spasms, slight intention tremor, anisoreflexia of the arms and legs, decrease or absence of abdominal reflexes). In a number of observations, a hypoxic test (B.A. Korolev, V.A. Belyankin) was given on the 9th or 10th day of reactivation after partial normalization of neurological status. Under the influence of hypoxic load, the neurological symptomatics recurred temporarily, usually in the form of elements of the "dextral pyramidal insufficiency" syndrome. /146

Electromyographic examinations made on the 7th or 8th day of motor reactivation showed a decrease in the amplitude of the muscle biopotentials under maximum exertion. This was most

conspicuous in the muscles of the lower leg. These changes might be related either to muscular atrophy or to anoxia. Asymmetry of the muscle biopotentials at maximum exertion was noted simultaneously: the oscillation amplitude was lower on the right than on the left side. This might indicate predominance of paretic effects in the right extremities, but tells us nothing of its nature (myogenic or neurogenic, and, if the latter, whether of peripheral or central origin). On the other hand, the detection of simultaneous electrical activity in agonists and antagonists on analysis of the electromyograms suggested disturbances of the reciprocal innervation. According to the classical electromyographic studies, this reciprocity disturbance would be regarded as proof of affection of the central neuron. Thus, the features of the EMG changes that we observed under the influence of prolonged hypodynamia confirm the presence of signs of the "dextral pyramidal insufficiency" syndrome in the subjects.

Analysis of the nature and extent of manifestation of the various neurological disorders during hypodynamia and under subsequently applied loads indicated substantial differences in the effectiveness of the preventive measures taken. If the neurological disorders in the 5 groups are characterized in terms of a few of the most conspicuous neurological signs, whose manifestations can be rated on a point scale, the most serious disturbances (in group I) total 6 points. The second group scores 5 points, the third 1 point, and the fourth and fifth groups 2 points each. Substantial differences are encountered in the attempt to use such criteria as disturbance to higher nervous activity, oral-automatism reflexes, and the interhemispheric-asymmetry phenomenon as a basis for rating the success of prophylaxis. Thus, for example, the first signs of functional insufficiency of the dominant hemisphere (the "dextral pyramidal insufficiency syndrome") were noted on the 20th (B-k), 20th (B-y), and 32nd (G-y) days for the group II subjects. Among the group III subjects, these signs did not appear at all in one, and in the other two they made their appearance only on the 53rd day. /147
In group IV, they appeared on the 20th day in one subject, on the 30th in another, and on the 46th in the third. In group V, the first manifestation of the interhemispheric asymmetry phenomenon appeared on the 30th day in one subject, on the 20th in the second, and on the 46th day in the third.[1]

The effort to secure maximum prophylaxis of hypokinetic disorders led to the use of a whole set of preventive measures in series IV and V. Nevertheless, to judge from the neurological disorders, these measures cannot be regarded as fully effective. Moreover, in drawing over-all conclusions from the neurological data, a better mark must be given not to the last two groups, but

[1]Functional insufficiency of the dominant hemisphere was observed in 14 out of 16 subjects. In series I, it failed to appear in one subject.

to the third. One reason for this may have been that comparatively little attention was given to development of measures to prevent disturbances to the regulation of nervous activity and to the regulation of metabolic-endocrine functions under conditions of hypodynamia. In our opinion, differentiated physical exercises designed to condition sensomotor postural reactions, including the standing, walking, and support reactions, are indicated for prevention of muscular disorders (atrophy, hypotonia, and loss of strength) and negative orthostatic vascular changes. Further, it would appear advisable to give the left extremities preferential or additional physical loads in connection with our developing hypothesis of the pathogenesis of the interhemispheric-asymmetry phenomenon.

The next prophylactic "bottleneck" is the inadequate study that has been given to disturbances of regional cerebral hemodynamics in hypodynamia and the absence of recommendations for their prevention. The occlusion conditioning given subjects of groups IV and V was apparently helpful in this respect (these subjects had no pronounced oral-automatism reflexes), but it did not prevent the development of the interhemispheric-asymmetry phenomenon.

In our opinion, autogenous training also deserves attention. The experience accumulated at our clinic in the use of autogenous training for the treatment of neurological patients indicates that this method has a normalizing influence on the regulation of vascular tone. It may be precisely because of the autogenous conditioning that the group III subjects produced superior neurological indicators. The only reservation to be voiced here is that it is not the generally accepted autogenous conditioning techniques, but the psychotonic modification that is indicated for the conditions of prolonged spaceflight.

CHANGES IN CERTAIN HUMAN MOTOR FUNCTIONS AFTER PROLONGED HYPODYNAMIA

V.S. Gurfinkel', Ye.I. Pal'tsev, A.G. Fel'dman, and A.M. El'ner

ABSTRACT: Prolonged hypokinesia results in disturbance of motor automatisms (synergies), as manifested in changes in such coordinated acts as standing up and walking and in the innervation relationships on which they are based. The physical-conditioning methods used in the experiments were quite effective in prevention of gross motor disturbances.

It has been shown in numerous studies that prolonged hypodynamia results in muscular atrophy and lowered muscular strength, static and dynamic endurance, and muscle tone. There are reasons to assume that prolonged limitation of motor activity affects not only muscular strength, but also the preservation of motor habits.

The objective of the present study was to investigate the influence of prolonged hypodynamia on the retention of such motor habits as maintaining vertical position, walking, and rising from the supine position and the innervation relationships (crossover effects in the spinal cord, vestibulospinal effects) on which these habits are based, and to evaluate various ways and means of preventing hypokinetic disturbances. The movements cited above were selected because they are to a considerable degree automatic and practically independent of voluntary intervention under ordinary conditions.

EXPERIMENTAL METHOD

For the static study, we used the stabilography method (Babskiy et al., 1952), which consists in registering the support reaction that reflects displacement of the body's general center of gravity in the sagittal and frontal planes. The sensitivity of the instrument makes it possible to register displacements down to tenths of a millimeter. This permits inferences as to the statics of the individual in his accustomed pose. The oscillations of the body's general center of gravity were investigated in each subject in his habitual attitude with his eyes closed and opened. The amplitude, frequency, and nature of the oscillations were considered in evaluating the stabilograms. Deep-breathing

exercises and raising of the arms were used as functional loads that complicated the problem of maintaining equilibrium. In these cases, the respiratory movements of the rib cage, the movements of the arms at the shoulder joint, and the electrical activity of the leg muscles and the anterior part of the deltoid were registered in addition to the stabilograms (Belen'kiy et al., 1967).

The kinematics of walking was investigated by registering the angles at the joints (hip, knee, ankle) and the times at which the heel, middle of the sole, and ball of the foot contacted the supporting surface (podogram). These records were obtained with /149
a telemetry system designed and built by V. Telesnin. Walking dynamics was studied by registering the support reactions — the vertical and horizontal components of leg pressure — with load dynamographs. For study of the kinematics and dynamics of walking, the subjects walked with their eyes open and closed along a track of which the dynamographs formed a part. The following indices were analyzed: evenness of gait, stability of the individual elements of the gait (transfer and support phases, proportions of movement phases in the joints).

In the study of the crossover effects in the spinal cord that accompany reflex activation of the corresponding leg muscles (gastrocnemius, quadriceps), we used a technique in which the function state of the spinal-cord segmental apparatus is tested monosynaptically (Gurfinkel', Pal'tsev, 1965). In these experiments, tendon reflexes were initiated with two electromagnetically operated mallets as the subject sat in a convenient seat, first on one leg (conditioning reflex), and then, after a brief interval of time (1-300 msec), on the other (testing reflex). The strength of the testing reflex was evaluated from the amplitude of the electromyographic response. The Achilles reflex was chosen as the conditioning reflex in some experiments, and the knee-jerk reflex in others; the knee reflex was the testing reflex in all cases.

The vestibulospinal effects were studied with an apparatus developed in our laboratory. The subject was positioned conveniently in a tilting seat (Fig. 1). The seat was held in its initial position by means of a mechanical lock (ML), which coupled to the seat rod on one side and was attached to a fixed base on the other. The angle of the sitting plane relative to the vertical was about 45° in the initial position. The subject's lower legs, flexed at a 110° angle, rested on special supports. Without warning the subject, the mechanical lock was opened and the seat tilted quickly on its horizontal axle under its own weight and that of the subject. The rotation angle was 17°, and the tilting motion took about 150 msec. The rotation of the seat was registered with a potentiometric goniometer (G) coupled to the seat's pivot axis. The functional state of the segmental apparatus was tested with a knee-jerk or Achilles reflex at various points in time after the beginning of the rotation, using

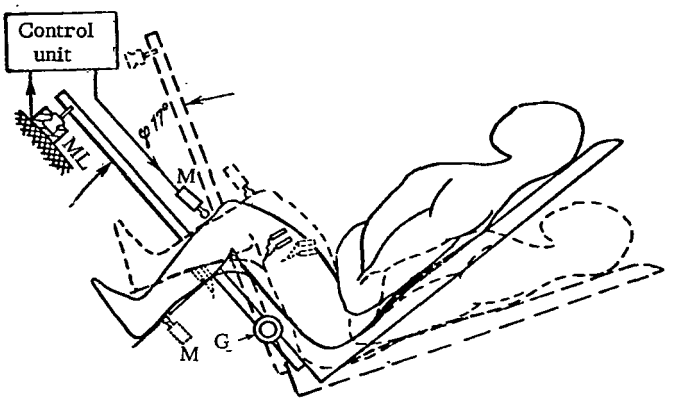

Figure 1. Diagram of Apparatus for Study of Vestibulospinal Effects. Symbols Explained in Text.

the electromagnetic mallet (M).

The synergy of the rising movements (Pal'tsev, El'ner, 1966) and hand tremor (Gurfinkel' et al., 1959) were also studied.

Subjects participating in experimental series II-V were investigated. In series II and III, the motor functions were studied on the first day after termination of the confinement to bed, the next day, and after one month. The subjects who participated in series IV and V were also examined before the experiment was started.

RESULTS

It will be convenient to set forth the results separately for each experimental group in view of the program differences.

Series II (subjects B-y, B-k, G-y). On the day on which the confinement to bed was terminated, all subjects of this group showed a sharp loss of stability of the body in the standing position. The amplitude of the oscillations of the body's general center of gravity had increased by a factor of two or more by comparison with the norm. Particularly conspicuous stability disturbances were noted in B-y, for whom the average amplitude of the body's oscillations was 3.5 times the norm (2.5-3.0 mm). The stabilograms of these subjects showed distinct high-frequency oscillations corresponding to the frequency of the physiological tremor (9-12 Hz), which do not usually appear under normal conditions under the registration conditions used. Continuous registration over 2-3 minutes showed a rise in the oscillation amplitude, indicating rapid fatiguing. The frequency of the stabilogram main waves varied insignificantly. Only in subject B-y

was there a distinct drop in oscillation frequencies; it was found here that the body's general center of gravity was moving in the sagittal plane in the rhythm of respiration (Fig. 2). We have never observed this stabilographic pattern in healthy individuals. On deeper breathing, all subjects showed respiratory oscillations of the center of gravity (Fig. 3). Resumption of ordinary respiration was accompanied by the disappearance of these respiratory waves. Stability deteriorated considerably in all subjects of this group when equilibrium was disturbed by raising the arms; this was manifest chiefly in the longer time required for recovery of the initial

/151

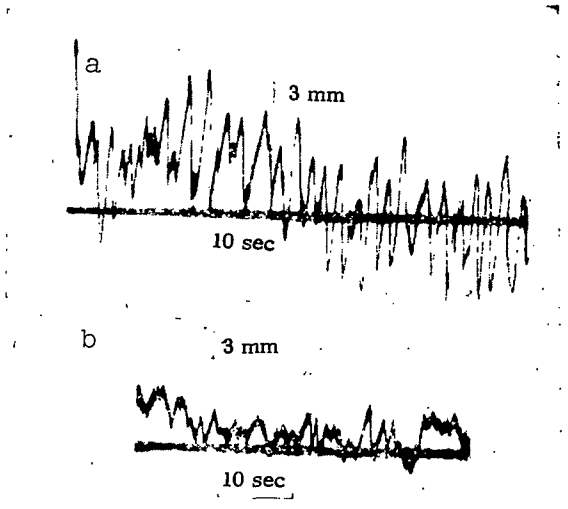

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Figure 2. Oscillations of Body's General Center of Gravity (Sagittal Stabilogram) for Subject Standing in Accustomed Vertical Attitude.

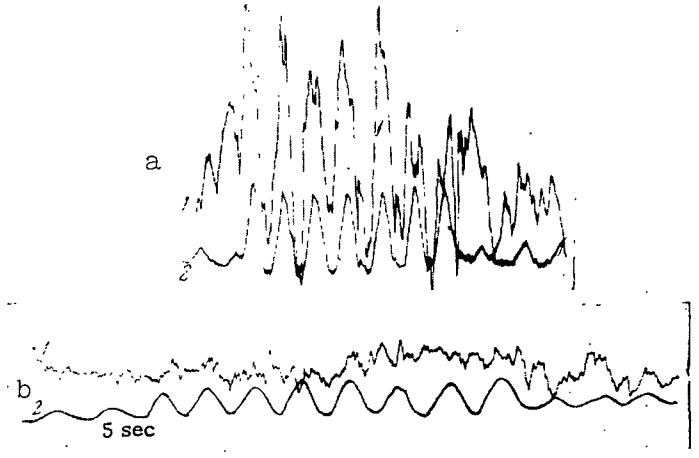

Figure 3. Oscillations of Body's General Center of Gravity During Deep Breathing. 1) Sagittal stabilogram; 2) pneumogram; a) on day of release from confinement to bed; b) one month later.

oscillation amplitude of the body's general center of gravity. Here we noted that there was no activation of the leg and trunk

muscles in anticipation of the main movement (Fig. 4).

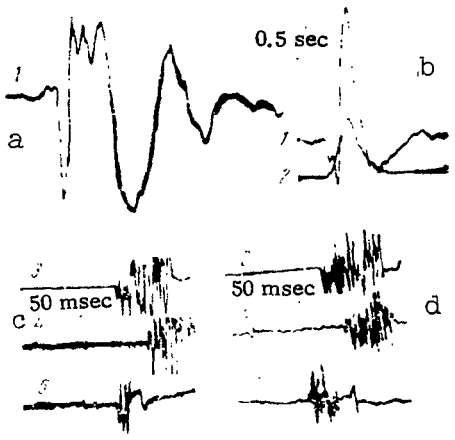

Figure 4. Oscillation of Body's General Center of Gravity (a, b) and EMG (c,d) on Raising the Arms. a, c) on the day of termination of confinement to bed; b, d) one month later; 1) sagittal stabilogram; 2) mechanogram of arm-raising movement; 3) EMG of right deltoid muscle; 4) EMG of left biceps femoris; 5) EMG of right biceps femoris.

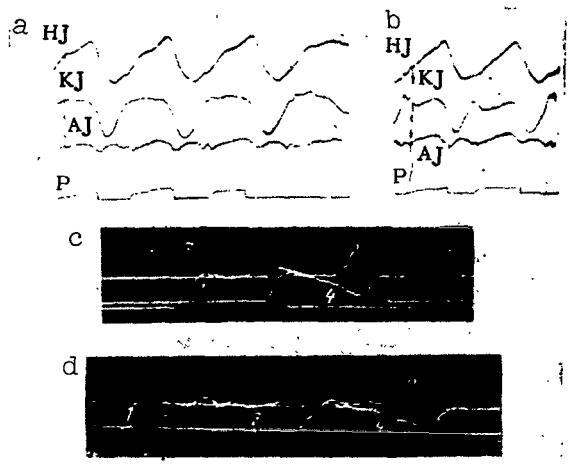

Figure 5. Analysis of Walk. a, c) Movements in hip (HJ), knee (KJ), and ankle (AJ) joints and podogram (P); a) on day of termination of confinement to bed; c) one month later. The arrow indicates the direction of flexure in the corresponding joint. Support reactions in walking on the day of release from bed confinement with eyes open (c) and closed (d); 1, 2) vertical components; 3, 4) horizontal components.

/153

Studies made of the kinematics and dynamics of walking indicate preservation of the basic features of this form of locomotion. At the same time, the following changes were detected: 1) considerable variations in step length; 2) a decrease in the amplitudes of motions in the joints; 3) lowered stability of the body in motion; 4) lack of smoothness in the motions in the ankle joint. These changes were especially conspicuous in the first few steps taken after release from bed confinement. They were manifested to a greater degree when the subjects walked with their eyes closed: shorter steps, longer times with the weight on both feet, and the appearance of a number of other signs that characterize the gait of these subjects without visual feedback as cautious and unsteady. This is indicated by the lower amplitude of the dynamic overshoots in the vertical component of the support reactions, the longer time taken to roll up onto the ball of the foot, and the slower tempo of the gait (Fig. 5).

Distinct departures from normal were detected in all subjects of this group on analysis of crossover effects (Fig. 6a). When

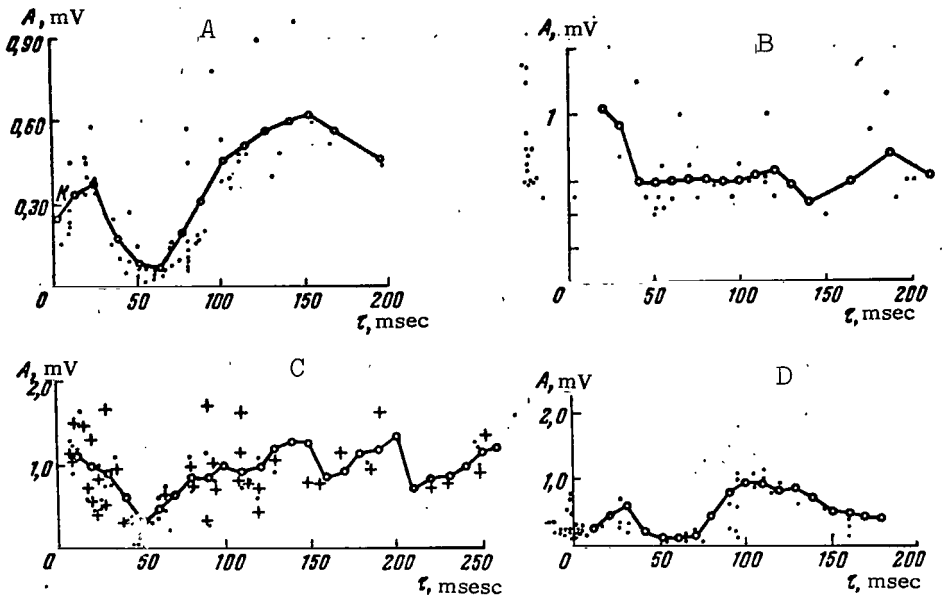

Figure 6. Amplitude of Testing Knee-Jerk Reflex as a Funct on of Time Interval Between this Reflex and the Conditioning Reflex on the Opposite Leg. A) Control subject (norm); B) subject B-y on the day of release from bed; C) subject B-y two days later; D) subject B-y one month later.

knee-jerk reflexes were evoked in these subjects against a background of enhanced reflex excitability of the spinal cord, both the inhibiting (with delay times of 40-90 msec between reflexes) and the enabling (with delay times of 100-200 msec between reflexes) crossover components were much weaker. They were totally absent in one of the subjects (B-y) (Fig. 6b).

Reexaminations indicated that certain indices to the state of the motor sphere improved even during the first day after release from bed confinement. A progressive improvement could be noted over the first few days (Figs. 5 and 6c). Even a month later, however, recovery was not complete (according to data from our studies). Thus, the crossover effects had not been completely restored (Fig. 6d), and static disturbances, though minor, still remained in response to tests.

We have dwelt at some length on description of the results of tests on these subjects because the disturbances to the motor functions were most pronounced in this group.

Series III (subjects K-v, V. M-k, M. M-k). Stability in the normal position was normal in all subjects of group III; nor were there any "respiratory" oscillations of the body's general center

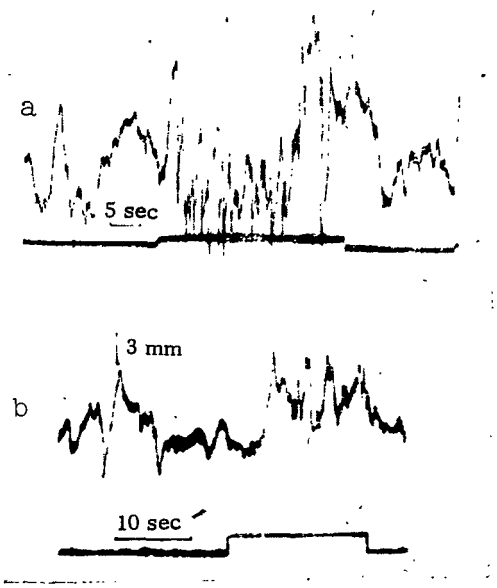

Figure 7. Oscillations of Body's General Center of Gravity with Eyes Closed (Mark on Lower Line) on the Day of Release from Confinement to Bed (a) and One Month Later (b).

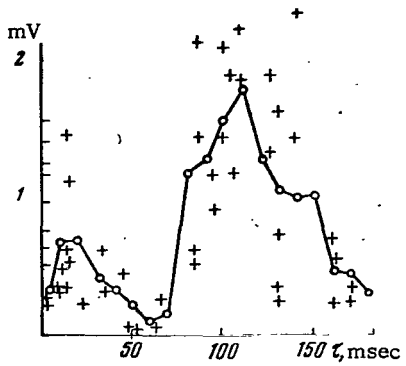

Figure 8. Amplitude of Testing Knee-Jerk Reflex as a Function of Time Interval Between this Reflex and the Conditioning Reflex on the Opposite Leg (Subject M. M-k). Symbols Same as in Fig. 6.

/157

/156

/155

of gravity. Static disturbances associated with deep breathing and arm raising in the vertical position occurred in two subjects (K-v, M. M-k), but they were less pronounced than in the group II subjects. Subjects K-v and V. M-k showed a distinct reaction to closing of the eyes, with a quick return of the oscillation amplitude of the body's general center of gravity to the initial value when the eyes were subsequently opened (Fig. 7). Moderate disturbances to the gait appeared in the form of variable length of the first few steps, reduced amplitude of the motions in the joints, and, in walking with the eyes closed, hesitation when the weight was on both feet and a slower gait. The walking disturbances were more clearly manifested in K-v. The departures of the crossover effects from normal were insignificant among the subjects of this group (V. M-k, M. M-k) (Fig. 8). The crossover effects were not investigated in K-v because of pronounced hyporeflexia. The disturbances described above were much less pronounced on the third day after termination of confinement, and a month later they had vanished in all subjects except K-v. After a month, this subject still showed mild static disturbances in response to testing and walking abnormalities in the form of jerky movements in the ankle joint, which caused perturbations in the knee and hip joints.

Series V (subjects A-n, L-i, F-v). The group V subjects showed somewhat more pronounced static disturbances than those of group III. Thus, in two of them (A-n, F-v), stability in the

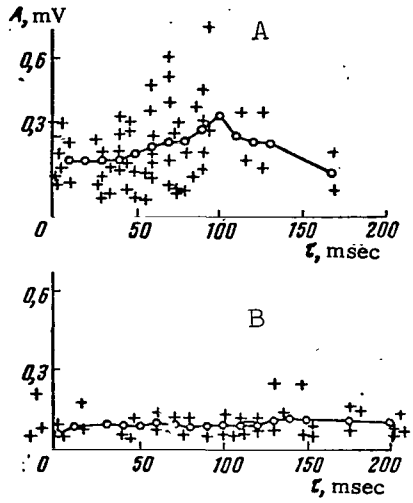

Figure 9. Diagrams of Testing Knee-Jerk Reflex Amplitude as a Function of Time Interval Between this Reflex and the Conditioning Achilles Reflex on the Opposite Leg for Subject A-n (A) Before the Start of the Experiment and (B) on the Day of Release from Confinement to Bed.

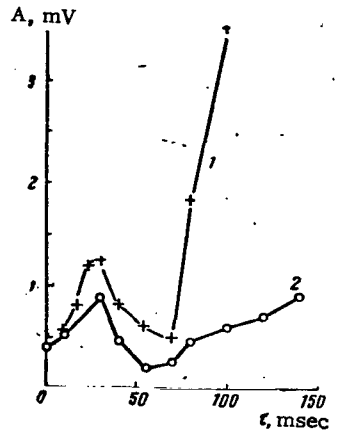

Figure 10. Diagram of Amplitude of Testing Knee Jerk Reflex (Ordinate) as a Function of Time Interval (Abscissa) Between Start of Seat Motion and Evocation of Reflex Before Start of Experiment (1) and on Day of Release from Confinement to Bed (2).

normal position was poor; it took a long time to return to the initial value in these same subjects after they opened their eyes. Static disturbances were produced in all subjects when they breathed deeply or raised their arms while standing. Walking disturbances were observed in all subjects of this group and were more clearly manifested than in group III; all of them lost stability while walking with eyes closed. The crossover effects were grossly disturbed: in two subjects (A-n, L-i), they were absent altogether (Fig. 9, a, b). Vestibulospinal effects were weak in all subjects, as indicated by the decrease in the second enabling component of the knee-jerk reflex in the backward fall. The synergy of the supine-to-standing movement was disturbed in two subjects (L-i, F-v); it was difficult for them to sit up without using their hands, not only from the horizontal plane, but also from a plane inclined to the plane of the legs. The tremor was modified (increased amplitude) in only one subject (L-i). One month later, all of the motor functions that we had studied had recovered completely.

Series IV (subjects A-v, B-v, K-ya). Two subjects (B-v, K-ya) showed poor stability in the normal position. In all of

them, the amplitude of the center-of-gravity oscillations took a long time to decrease to the initial value when the eyes were opened. Arm-raising static disturbances were noted in one subject (B-v), and disturbances in response to deep breathing in the other two (K-ya, A-v). Walking disturbances appeared in all subjects of this group and were manifested by the same signs as in the group V subjects. Crossover effects were also disturbed in all subjects: weakening and delay of the second enabling component. The vestibular spinal effects were weakened in two subjects (B-v, K-ya, Fig. 10), as in the group V subjects; they were normal in one subject (A-v). The synergy of rising was disturbed in all subjects — moderately in B-v and considerably in the others; it was impossible for them to do situps from a horizontal plane, and difficult from a plane inclined to the legs; in the latter case, the legs rose off the supporting surface in what is known as Babinskiy's asynergy. Tremor was modified in all subjects: the amplitude of the high-frequency component was approximately twice normal, and there was a substantial amplitude increase in the slow component. The normal crossover effects had not recovered fully in any of the subjects after a month (the second enabling component was reduced); in addition, slight walking disturbances persisted in one subject (K-ya) — reduced amplitude of the motions in the joints and a lengthened time with weight on both feet. The motor functions had otherwise recovered.

/156

/158

DISCUSSION

Let us examine the possible causes of the motor disturbances observed in our subjects. Lowered muscular strength and sensitivity do not appear to be responsible for these disturbances. Actually, static disturbances are observed when the body is upset by respiratory movements or sudden raising of the arms in patients who have sustained local brain injury, but in whom strength and sensitivity are fully intact, and whose leg motions are coordinated in other situations (El'ner, 1965); moreover, loss of leg-muscle strength is not accompanied by such static disturbances (Pal'tsev and El'ner, 1967). This justifies the assumption that disturbances to the coordination of the various muscle groups are behind the static defects described above, i.e., derangement of the synergies whose intent is to maintain the vertical position. One of these synergies is the synergy that supports maintenance of the vertical position when the arms are abruptly raised (Belin'kiy et al., 1967), as manifested in preparatory and compensating movements of the legs and trunk. For example, omission of the preparatory phase is accompanied by deterioration of stability (Pal'tsev, El'ner, 1967). Another example is the respiratory synergy (Gurfinkel' et al., 1966). Normal respiration is accompanied by displacements of individual parts of the body relative to one another, and this complicates conditions for maintenance of equilibrium in the standing position; the amplitude of these displacements is increased during deep breathing. Normally, the respiratory displacements of the trunk are compensated by

concordant movements in the hip joints, so that excessively wide /159
oscillations of the body's general center of gravity are prevented. These concordant movements do not occur during movements of the trunk when respiration is voluntarily suppressed, i.e., a kind of respiration-connected synergy is observed. We have also become convinced that injury to the frontal lobes is accompanied by motor-synergy disruption resulting in characteristic disturbances to stability in the standing position (Gurfinkel', El'ner, 1968). Another hypothesis that has been advanced is that this synergy may also be disturbed in healthy persons if they do not "use" it for a long time, and that it can be recovered like any other broken habit. Indeed, similar static disturbances (Figs. 2b and 3a) were observed in our subjects; they had diminished or disappeared some time (ranging from a few days to several weeks) after the return to normal motor activity.

In addition to balancing-reaction disturbances, we observed walking disturbances among our subjects, manifested in varying step length, decreased amplitude of the movements in the joints, lower stability of the body during motion, and lack of smoothness in the ankle movements. These changes were especially conspicuous when the subjects walked without visual afferentation (Fig. 5c). These changes gradually decreased after release from confinement to bed. The degrees to which they were manifested and the times to total recovery were different in different series. Such are the factual data on the walking disturbances. The question as to the physiological mechanisms of these disturbances remains unclarified. Here we can only point out certain considerations. First of all, our attention is drawn to the fact that groups II and III differ substantially in the walk-disturbance index. The modification of the crossover effects clearly correlates with this. In the series II subjects, who had the greatest difficulty in walking, the crossover effects were absent and were not recovered for a long time (Fig. 6, b, c, d); in the series III subjects, the gait changes were mild and the crossover effects had been retained (Fig. 8). The crossover effects have been regarded as the reflex basis of walking ever since publication of the work of Sherrington and especially of Graham-Brown. Our human research (see also Pal'tsev, 1967) gives reason to assume that the crossover effects are also related to walking in man and perhaps reflect the state of the locomotor synergy. We are therefore inclined to believe that the walking disturbances observed are due to decay of this synergy as a result of prolonged "disuse." The fact that certain parameters of the gait show improvement even after the first few dozen steps also tends to favor this hypothesis.

Other motor disturbances in our subjects were also associated with disordering of the synergies. Thus, some of the subjects were unable to sit up from the supine position without using their /160
hands; this symptom is known in the literature as Babinskiy's asynergy.

However, disturbance of the synergies was not the only cause of the motor disturbances in our subjects. There were signs of increased fatiguability. Thus, there was a substantial increase in tremor amplitude in some of the subjects; this was noted not only on specific registration of the tremor, but also on the stabilograms, in the form of oscillations with a frequency of 9-12 Hz, such as are not observed in the norm under the registration conditions used. Continuous registration of the standing position for 2-3 minutes caused an increase in the oscillation amplitude of the body's general center of gravity. In addition, some of the subjects showed distinctly what is known as Romberg's symptom – a sharp increase in the average amplitude of the body's general center of gravity when the eyes were closed (Fig. 7a). There is a possibility that the decreased vestibulospinal effects observed in the experiments were a factor in the genesis of this symptom (Fig. 10).

As we see from the exposition of the experimental results, the degree to which motor disturbances come into evidence depends in many respects on the conditions of subject motor activity in the various experimental series. More profound disturbances to the motor functions occurred in series II subjects, who did not receive special conditioning; one or another deviation from the norm was observed in all of them a month after release from bed confinement. These disturbances were manifested to a somewhat lesser degree in the series IV subjects, who exercised with the bicycle ergometer. In this case, only minor walking difficulties and disturbances to the crossover effects remained after a month. The mildest disturbances were noted in the subjects who exercised with the treadmill, especially those of series III; in all six of them, no deviations from the accepted norm could be detected a month after termination of the confinement to bed.

Thus, gross disturbances to the motor functions are prevented under the conditions of limited mobility by special conditioning, whose basic significance consists, in our opinion, in maintenance of previously developed motor habits – an important department of voluntary activity.

CONCLUSIONS

1. Prolonged hypokinesia results in disturbances to the motor automatisms (synergies), as manifested in disordering of such coordinated acts as standing, walking, etc., and the innervation relationships on which they are based.

2. The conditioning methods used in the experiments represent a rather effective means of preventing gross motor disturbances.

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/161

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CHANGES IN THE BIOCHEMICAL PECULIARITIES OF WALKING UNDER THE INFLUENCE OF HYPODYNAMIA ACCORDING TO ICHNOGRAPHIC DATA

V.G. Skrypnik

ABSTRACT: The locomotor act of walking was studied in six subjects before and after an experiment during which they were confined to bed in the supine position for an extended period. Studies of the gait of the subjects produced data indicating reconstruction of the original stereotype of walking. This was manifested in a relative shortening of the distance covered in a double step and the symmetry between its component elements... [leading] to a change in the habitual kinematics of the trunk and extremities and to disturbance of the ability to walk a straight line. Use of physical conditioning (bicycle ergometer and treadmill) as a prophylactic measure reduces but does not eliminate the detrimental effects of prolonged limitation of mobility. Use of the physical-conditioning appliances in the supine position during a prolonged limitation of mobility results in development of a new stereotype whose stability is greater (treadmill) the closer the similarity between the motions and load of the motor apparatus under the conditions of the acquired locomotor habit and the conditions of the experiment. Although the subjects then "break in" more slowly (treadmill), they show greater stability during locomotion immediately after the experiment.

The locomotor act was evaluated by ichnography with simultaneous motion-picture photography from the front and side in the healthy young individuals who participated as subjects in experimental series IV and V. For this purpose, the soles of each subject's feet were painted and he was asked to walk in his usual rhythm and in a specified direction along a paper strip. The locomotor act of walking was registered four times on four of six subjects: before the experiment, immediately after termination of the confinement to bed, and on the 3rd and 30th days. The diagram in Fig. 1 illustrates interpretation of the ichnograms.

The data secured prior to the experiment were taken as the "individual background norm" with which all subsequent measurements were compared. The original background for the length of

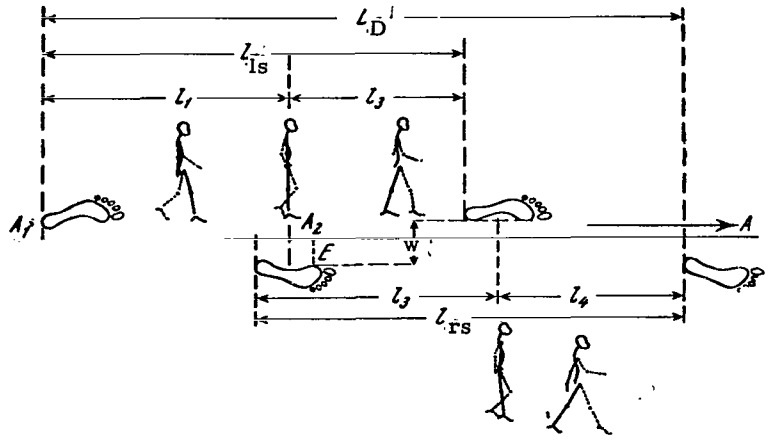

Figure 1. Diagram showing Measurement of Length of Step and its Component Elements on an Ichnogram. A_1A) Centerline guide on paper strip; A_2E) distance of foot from centerline; L_D) length of double step; l_{ls}) length of left single step; l_1) length of left half step backward; l_3(top)) length of left half step forward; l_{rs}) length of right single step; l_4) length of right half step forward; w) width of step.

the double step and its component elements was stated in a classification borrowed from M.F. Ivanitskiy's handbook (1948). Adoption of this classification was dictated by the position of the subjects on the horizontal suspended cot (Fig. 2). The background results recorded are given in Tables 1 and 2.

Exclusion of the visual analyzer results in shorter length characteristics of the walking step by an average of 5-6% in most subjects (see Table 2).

As we see from Table 2, the ratio between the length dimensions of B-v's double step for eyes-closed and eyes-open walking was 1.00 in all cases. This persistent stability of the ratio is combined in this individual with distinct flatfootedness (bear tracks). By his own account, this functional-morphological peculiarity of his feet causes him no discomfort even when he takes long walks, up to 20-30 km in a day.

Together with the above, stability and persistence of the ratios between all component elements of the full double-step cycle was observed before the experiment in all subjects as they walked with their eyes either open or closed (Table 3).

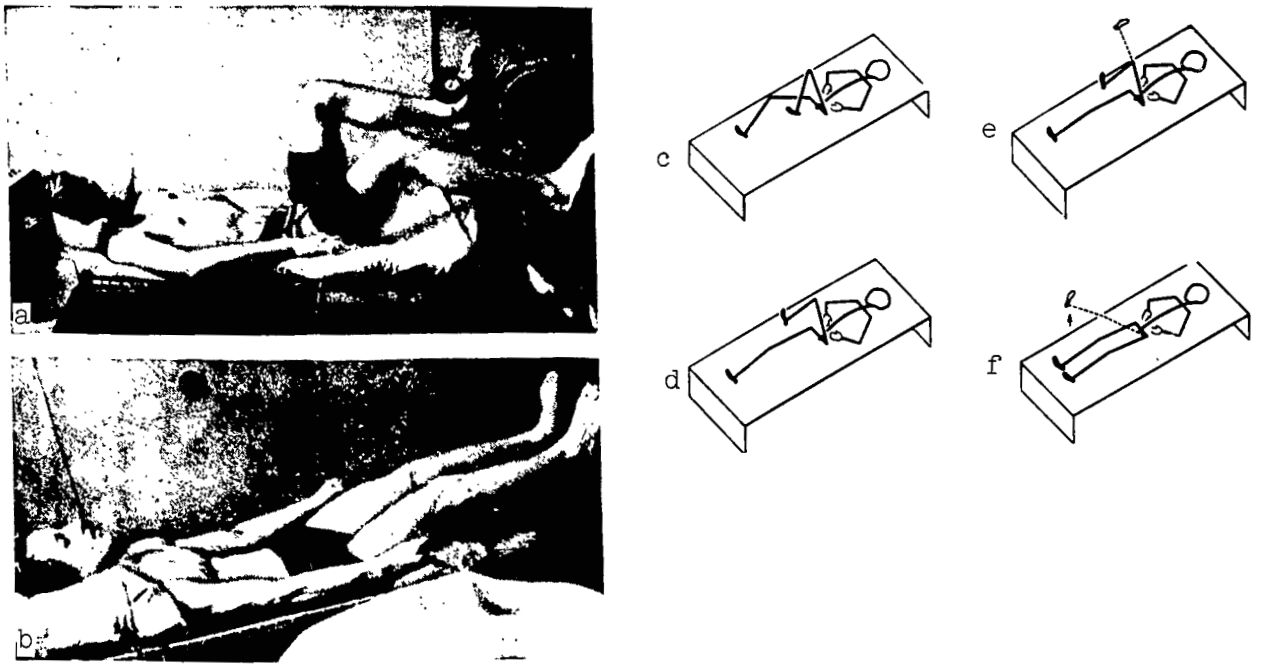

Figure 2. Positioning of Subject on Suspended Cot for Experiment. a) Position of subject in series IV; c,d) diagram showing arrangement of trunk and extremities in extreme positions during bicycle-ergometer exercising; b) position of subject in series V; e,f) diagram showing positions of trunk and extremities in extreme positions during treadmill exercising.

TABLE 1. LENGTH (in cm) OF DOUBLE STEP AND ITS COMPONENT ELEMENTS AS OBTAINED IN EYES-CLOSED WALKING BEFORE EXPERIMENT

Step and its elements	A-n	F-v	L-i	B-v	A-v	K-ya	Mean (M)	Deaviation from M	
								max.	min.
Length of double step L_D ..	228,0	227,5	210,2	210,5	216,0	216,0	217,85	+9,65	—7,35
Length of left single step $l_{l.s}$	150,0	151,2	138,6	137,5	147,0	142,0	144,38	+6,82	—6,88
Length of right single step $l_{r.s}$	151,3	153,0	140,4	144,5	144,2	143,5	146,15	+6,85	—5,75
Length of left half step backward l_1	87,5	87,9	75,9	77,0	82,5	78,2	81,50	+6,40	—5,60
Length of left haft step forward l_2	61,5	65,3	59,1	60,5	64,0	59,7	61,07	+4,23	—1,97
Length of right half step backward l_3	84,8	87,7	80,0	82,1	85,3	80,0	83,40	+4,30	—3,40
Length of right half step forward l_4	66,5	65,3	60,3	62,0	58,5	60,0	62,10	+4,40	—3,60

TABLE 2. RATIOS BETWEEN LENGTH DIMENSIONS OF DOUBLE STEP AND ITS COMPONENT ELEMENTS IN WALKING WITH EYES CLOSED AND OPEN (Background Data) /165

Ratio	A-n	F-v	L-i	B-v	Ayu-v	K-ya	M
L_D (c) : L_D (o)	0,91	0,92	0,96	1,00	0,90	0,95	0,94
$l_{l.s}$(c) : $l_{l.s}$ (o)	0,94	0,91	0,97	1,00	0,89	0,95	0,94
$l_{r.s}$(c) : $l_{r.s}$(o)	0,90	0,90	0,96	1,00	0,90	0,98	0,94
l_1 (c) : l_1 (o)	0,91	0,92	0,83	0,99	0,93	0,96	0,95
l_2 (c) : l_2 (o)	0,90	0,87	0,97	1,01	0,85	0,97	0,95
l_3 (c) : l_3 (o)	0,99	0,90	0,95	1,00	0,89	1,00	0,95
l_4 (c) : l_4 (o)	0,84	0,91	0,96	1,00	0,91	0,99	0,94

c,o) eyes closed and open; step lengths: L_D) double step; $l_{l.s}$) left single step; $l_{r.s}$) right single step; l_1) left half step backward; l_2) left half step forward; l_3) right half step backward; l_4) right half step forward.

TABLE 3. RATIOS BETWEEN LENGTH INDICES OF DOUBLE STEP AND ITS COMPONENT ELEMENTS DURING WALKING (Background Data) /166

Ratio	A-n	F-v	L-i	B-v	A-v	K-ya	M	Deviations from M	
								max.	min.
Eyes open									
$l_{l.s} : L_D$	0,66	0,66	0,66	0,65	0,68	0,66	0,66	+0,02	—0,01
$l_{r.s} : L_D$	0,66	0,67	0,67	0,68	0,67	0,66	0,67	+0,01	—0,01
$l_{l.s} : l_{r.s}$	0,99	0,99	0,98	0,95	1,02	0,99	0,99	+0,03	—0,02
$l_1 : l_{l.s}$	0,58	0,58	0,55	0,56	0,56	0,55	0,56	+0,02	—0,01
$l_2 : l_{l.s}$	0,41	0,43	0,43	0,44	0,43	0,42	0,42	+0,02	—0,01
$l_3 : l_{r.s}$	0,70	0,74	0,78	0,79	0,78	0,76	0,75	+0,04	—0,05
$l_4 : l_{r.s}$	0,56	0,57	0,57	0,57	0,59	0,55	0,57	+0,02	—0,02
$l_4 : l_3$	0,44	0,43	0,43	0,43	0,47	0,42	0,44	+0,02	—0,01
	0,78	0,74	0,75	0,75	0,69	0,75	0,74	+0,04	—0,05
Eyes closed									
1: L_D	0,68	0,66	0,67	0,65	0,67	0,66	0,66	+0,02	—0,01
^2L_D	0,66	0,66	0,67	0,69	0,66	0,68	0,67	+0,02	—0,01
$l_{l.s} : l_{r.s}$	1,03	0,99	1,01	0,94	1,01	0,97	0,99	+0,04	—0,04
$l_1 : l_{l.s}$	0,57	0,59	0,58	0,55	0,58	0,55	0,57	+0,02	—0,02
$l_2 : l_{l.s}$	0,43	0,41	0,43	0,45	0,41	0,43	0,42	+0,02	—0,02
$l_2 : l_1$	0,75	0,70	0,74	0,80	0,71	0,78	0,75	+0,05	—0,05
$l_3 : l_{r.s}$	0,57	0,57	0,57	0,58	0,57	0,58	0,58	+0,03	—0,01
$l_4 : l_{r.s}$	0,41	0,43	0,43	0,43	0,41	0,42	0,42	+0,04	—0,01
$l_4 : l_3$	0,67	0,75	0,75	0,75	0,74	0,74	0,73	+0,02	—0,06

TABLE 4. CHANGES IN RELATIVE LENGTH OF DOUBLE STEP AND ITS COMPONENT ELEMENTS IN SERIES IV SUBJECTS AFTER THE EXPERIMENT

/167

	Subject and date of study								
	B-v			A-v			K-ya		
	June 20	June 22	July 17	June 20	June 22	July 17	June 20	June 22	July 17
	Eyes open								
$l_{l.s}$	0,845	0,991	1,064	0,845	0,836	0,966	0,716		1,020
l_1	0,824	1,006	1,105	0,827	0,887	1,013	0,731		0,996
l_2	0,857	0,975	1,014	0,873	0,781	0,923	0,758		1,059
$l_{r.s}$	0,805	0,985	1,008	0,845	0,835	0,988	0,881		1,004
l_3	0,887	0,984	1,010	0,893	0,833	0,942	0,797		1,046
l_4	0,787	0,997	1,010	0,838	0,813	1,058	0,578		0,970
L_D	0,797	0,983	1,043	0,856	0,839	0,996	0,701		1,020
	Eyes closed								
$l_{l.s}$	0,785	0,934	0,840	0,674	0,733	0,864	0,604		0,774
l_1	0,805	0,971	0,858	0,659	0,752	0,921	0,639		0,773
l_2	0,788	0,901	0,640	0,879	0,764	0,794	0,558		0,786
$l_{r.s}$	0,755	0,859	0,736	0,651	0,785	0,884	0,572		0,770
l_3	0,736	0,925	0,821	0,775	0,841	0,847	0,570		0,692
l_4	0,687	0,818	0,620	0,550	0,718	0,931	0,467		0,670
L_D	0,760	0,898	0,781	0,671	0,861	0,890	0,581		0,756

Study of the ichnograms after the experiment showed disturbances of the initial background for both types of walking – eyes-open and eyes-closed – for every one of the subjects. Common features of these changes are the shorter length dimensions of the double step and its component elements, the change in the proportional relationships between them, and deviation from the specified direction of motion. These changes in the step are combined, according to the films, with increased oscillation of the torso in the transverse and longitudinal directions. This set of disturbances to the locomotor act is more distinctly manifest immediately after termination of the experiment in series IV, i.e., among those subjects who exercised on the bicycle ergometer. Immediately after standing up, these subjects walked with short steps, moving with difficulty and dragging their feet, scraping the heel and then the ball of the foot, and leaning the torso in the direction of the leg carrying the weight. Swaying from side to side and balancing with their torsos, they zigzagged to either side of the line they were supposed to walk. The length characteristics of the double step and its component elements in eyes-open walking immediately after termination of the experiment were found in all three measurements to be lower than the figures registered under the same walking conditions during the background study. Table 4 indicates the extent of this decrease for eyes-open and eyes-closed walking.

/165

We see on comparison of the data given in Table 4 that, in contrast to the background, symmetry is disturbed to a greater degree during walking with the visual analyzer excluded than when it is in operation. At the same time, our attention is drawn to the fact that the process of "recovering" the initial level and stereotype of eyes-open walking was more rapid in B-v and K-ya than in A-v.

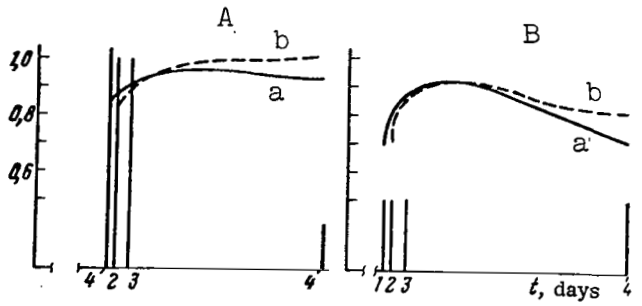

Figure 3. Variation of Relative Length of Left Single Step in Subjects After Termination of Bed Confinement, During Walking with Eyes Open (A) and Closed (B). a) Series V subjects; b) series IV subjects; 1, 2, 3, 4) measurements corresponding to dates given in the tables; ratios of the various measurements to the background are indicated on the axis of ordinates.

In the series V subjects, who had exercised on the treadmill, the entire complex of disturbances to /166
the locomotor act was much less pronounced than in series IV immediately after release from confinement to bed. However, the rate of "recovery" was slower from the 3rd through the /167
30th day. This was most clearly evidenced in the step-length indicators, which remained below the initial level at the times of measurement (Table 5). The tabular indications can be demonstrated graphically (see Fig. 3).

The diagram shows that although the relative decrease in the length of the left single step on leaving bed was larger among the series IV subjects, its "recovery" is considerably more rapid than in the series V subjects. The data given in the tables and illustrated by the diagram give reason to assume the presence of a direct dependence between the shortening of step length immediately after the experiment and its subsequent "recovery." The greater the /168
decrease in the length characteristics of the double step on the series IV and V ichnograms during the recovery period, the higher and more rapid is the tempo of the subsequent lengthening. The apparent reason for this paradox is that the difference in the primary shortening between the series IV and V subjects is a function of the strength of the motion stereotype developed during the experiment and, consequently, the physical conditioning facilities. The nonuniform shortening of the half-steps, and the backward half-step in particular, stems from inadequacies of the methods used in each form of exercise. Treadmill exercising results in more stable reconstruction of the initial stereotype and symmetry of the leg motions, less shortening of the original half-step lengths immediately after termination of bed confinement, and, at the same time, a slower "recovery."

TABLE 5. CHANGES IN RELATIVE LENGTH OF DOUBLE STEP AND ITS COMPONENT ELEMENTS AFTER EXPERIMENT IN SERIES V SUBJECTS

/168

Parameter	Subject and date of study								
	A-n			F-y			L-i		
	June 19	June 22	July 17	June 19	June 22	July 17	June 19	June 22	July 17
	Eyes open								
$l_{l.s}$	0,893	0,930	0,900	0,707	0,895	0,867	0,774		0,977
l_1	0,877	0,897	0,875	0,716	0,923	0,815	0,826		0,997
l_2	0,992	0,992	0,951	0,744	0,870	0,894	0,793		1,142
$l_{r.s}$	0,948	0,948	0,913	0,762	0,885	0,863	0,847		0,980
l_3	0,981	0,983	0,943	0,787	0,906	0,934	0,830		0,972
l_4	0,919	0,902	0,878	0,597	0,854	0,837	0,859		1,012
L_D	0,900	0,921	0,900	0,755	0,897	0,914	0,847		0,985
	Eyes closed								
$l_{l.s}$	0,977	0,937	0,743	0,935	0,826	0,601	0,573		0,795
l_1	1,007	0,924	0,698	0,715	0,863	0,687	0,717		0,840
l_2	0,928	0,975	0,817	0,565	0,760	0,474	0,487		0,830
$l_{r.s}$	0,960	1,028	0,814	0,696	0,891	0,550	0,589		0,761
l_3	0,927	0,960	0,783	0,685	0,829	0,616	0,593		0,835
l_4	1,018	1,127	0,748	0,707	0,970	0,647	0,653		0,797
L_D	0,980	0,990	0,761	0,687	0,870	0,595	0,637		0,819

When the subjects were interviewed after the experiment, they all complained of general weakness and pains in the muscles, and especially in the gluteal, gastrocnemial, and perineal groups and, /169 in the series V subjects, also in the adductor muscles of the thigh.

It was established on inspection of the films that when they walked after the experiment, all subjects, and especially those of series IV, made an effort to keep their feet as close to the floor as possible, balancing with the torso and leaning onto the supporting leg. They had difficulty in walking a straight line.

The nature of the disturbances to the locomotor act that were observed after the long (70-day) confinement to bed provides a basis for the assumption that the unusual and impoverished proprioceptation of the supporting-motor apparatus, with the decrease in its accustomed vertical component, the deconditioning of the postural muscles and especially those of the pelvic girdle and the gastrocnemial and perineal muscles are linked with:

a) development of a new stereotype in the process of conditioning during the experiment;

b) overloading of the spinal, subcortical, and cortical

centers by proprioceptation after termination of the experiment, owing to the increase in its vertical component, and

c) the need to "break in" to the initial locomotion stereotype, which had been reconstructed during the experiment.

This is confirmed by the difference in the proportional symmetry of the double-step elements and by the change in the structure of the gait, especially with the eyes shut, in accordance with the habits that the subjects of each series developed during the experiment.

CONCLUSIONS

1. The initial state of the subjects is characterized by stability of the walking stereotype with the eyes either closed or open, and by constancy of the proportions between the component elements of the double step.

2. Eyes-closed walking tends to shorten all length characteristics of the step, but does not affect the proportions between them.

3. After the experiment, all subjects showed disturbance of the habitual walking stereotype, with the eyes both open and closed.

4. The basic features of the changes from the initial walking background were as follows:

a) a decrease from the initial level in the double, single, and half-steps;

b) change in the proportions between the component elements of the double step;

c) reduced ability to walk a straight line;

d) development of a shuffle.

5. During the experiment, the series V subjects developed a stronger new walking stereotype than did those of series IV. /170

6. Immediately after termination of the experiment, the initial walking stereotype was disturbed to a greater degree in the series IV subjects, who had exercised on the bicycle ergometer, than in those of series V, who had exercised on the treadmill.

7. The process of recovering the initial length dimensions of the double-step elements and their proportional relationships advanced more rapidly in series IV than in V, and was complete a

month after the experiment.

8. In eyes-open walking after the experiment, shortening of the half-steps, forward in series IV and backward in series V, predominates in both groups against a general background of shorter step lengths.

9. The nonuniformity and asymmetry in the shortening of the half-steps after the experiment was probably due to inadequacies of the exercising technique.

10. To reduce the effect of hypokinesia on walking, it is advisable to increase the vertical component of proprioceptive afferentation for the entire supporting-motor apparatus, and to use exercising machines to impose loads on the gluteal, gastrocnemial, and perineal muscle groups.

11. Long-term use of regular monotonous movements that simulate walking during the 70-day confinement to bed resulted in reconstruction of the original walking stereotype after the experiment.

12. The strength of the walking stereotype reconstructed during confinement to bed depends directly on the exercise facilities used, but was greater in series V than in IV.

SUMMARY

Use of the treadmill and bicycle ergometer as physical-conditioning aids for those subject to long-term hypodynamia has various effects on the changes in the habitual walking stereotype and its "recovery." During the first few days after termination of the experiment, the series V subjects were better able to walk unassisted than were those of series IV. To preserve a gait closely similar to the initial level, it is necessary to combine both conditioning procedures. To eliminate hypotonia of the postural, gluteal, gastrocnemial, and perineal muscles, it is necessary to redesign the exercises performed by the subjects and create conditions that impose the greatest possible load on these muscle groups.

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STATE OF PSYCHIC ACTIVITY IN SUBJECTS DURING PROLONGED CONFINEMENT TO BED

/171

V.P. Bogachenko

ABSTRACT: Distinct changes in psychic state took place in subjects who were strictly confined to bed and did not perform physical exercises or receive medication during this confinement. These changes were less distinct in the group of individuals who performed epecially designed physical exercises. In the two series of experiments in which a composite set of prophylactic measures was applied, practically no changes in the psychic sphere were detected. The decisive factor in the development of the neuropsychic disturbances was the forced immobility.

We carried out a clinical investigation of the state of psychic activity in 16 healthy young individuals who were subjected to prolonged hypokinesia in five series of experiments.

Four individuals were studied in a strict bedrest regime (series I), three during bedrest with mixed medication (series II), and nine during bedrest with physical exercises (series III-IV).

In all series, a clear majority of subjects complained of painful sensations in the small of the back from the 2nd through the 5th or 6th day of hypokinesia (one of them was also troubled by discomfort in the muscles of the anterior abdominal wall). Subjects K-n and L-i registered no complaints during these days.

In series I of experiments, which were conducted under conditions of strict bedrest, the three subjects complained of general weakness and dizziness in response to turning the head from days 5-6 through 9-10 of hypodynamia. It should be noted that these complaints were registered not actively, but only when the subjects were interrogated in specific terms. During this time, despite the appearance of the painful sensations, all subjects remained in a good mood, submitted calmly to all forms of examination, including those involving discomfort, read newspapers and magazines during the day, conversed with one another on various subjects, and slept soundly at night, with infrequent awakenings.

At the end of the second week and the beginning of the third, the three subjects became somewhat irritable, reported that the hypodynamia was weighing heavily upon them, and expressed the

desire to get up. A "breakthrough" intervened at the end of the third week. Thus, Ch-y reported that "Before, I had the feeling that something was missing and I was getting bored with the hypodynamia, but now I feel better."

From days 40 to 45, Ch-y and M-s were observed to have fluctuations of mood with no particular reason: they were in a good mood in the morning, then became pensive for several hours, but had cheered up again by evening. When he was in a good mood, M-s would hum loudly, changing tunes rather frequently. However, these variations of mood did not interfere with the hypodynamic regime, produce generally disruptive behavior on the part of the subjects, or interfere badly with their sleep at night.

Beginning after 50 days and continuing to the end of the study, Ch-y manifested irritability from time to time: in his own words, he had difficulty putting up with ordinary chatter /172
in the ward or the voice of an announcer in his headset; at the same time, he watched patiently through television broadcasts, read fiction, and remained superficially calm.

During the period after hypodynamia, when they were resuming active motion, the subjects complained of pains in the muscles of their feet, shanks, and thighs. During their first day of freedom, they complained of feeling bad and "internally irritable," but retained outward equanimity. Their mood improved progressively during the days that followed, and the subjects became more cheerful and active.

Pronounced disturbances to neuropsychic activity appeared in only one subject (K-s). In his case, the 20th day of hypodynamia was marked by the appearance of headaches, dizziness, nausea, and general lassitude. His mood deteriorated sharply, he broke into tears at frequent intervals, "could not concentrate on anything," and found it "hard to think." At the same time, he experienced a desire to move and could lie quiet no longer. On the preceding two nights, he had slept little and his sleep was fitful. The otorhinolaryngologist had established signs of irritation of the vestibular apparatus. On the next day, no clear signs of vestibular disturbance could be found, but the subject's mood remained depressed; he was unwilling to answer questions, his voice was dull and monotonous, his responses laconic; his eyes teared at all times. He complained of dull headaches and a hot, heavy feeling in the head. Distinct tremor of the fingers of the outstretched hands and general hyperhidrosis were noted. He categorically refused to continue the study, since he could no longer stand his morbid sensations.

This neurotic reaction in K-s was so strong that it was necessary to terminate hypokinesia. For the first few days after being told he could move as he pleased in his bed, K-s complained not only of pains in the muscles of his extremities, but also of

stuffiness in the head, general weakness, and rapid tiring; he reported that he found it difficult to think. His arms and legs remained in continuous motion ("I can't stop myself from moving them."). His mood began to improve on the 3rd day, and he had no further complaints after the 5th, when he began to reproach himself for breaking off the experiment. His mood remained good thereafter. Finally, it should be noted that one of the four series I subjects (K-n) showed no marked neuropsychic disturbances throughout the entire period of hypodynamia.

As we noted above, three individuals (seres II) received a mixture of medications consisting of securinine, caffeine, and amphetamine on a definite schedule. During the intervals when they were not under the immediate effects of the medication, subject G-y showed no marked psychic changes, but B-y and B-k showed occasional symptoms of emotional instability from time to time. They did not become pronounced until the end of the third week in hypokinesia, taking the form of instability of mood and irritability in addressing the attending personnel. /173 Such symptoms were observed for two weeks. Thereafter, the subjects remained superficially calm and polite through to the end of hypodynamia, read fiction, and watched television. When questioned specifically, however, B-y and B-k reported that they were fed up with lying there and being examined, and that it was becoming hard to stand a pinprick.

During periods when they had taken the medication, all three volunteers showed distinct neuropsychic disturbances from the first or second day on: sleep came slowly at night and was superficial, fitful, and accompanied by nightmares; during the day, their mood improved, they experienced an inrush of strength, conversed in loud voices, laughed for no apparent reason, and sang; quickened speech tempo and motor disinhibition were noted. On the 3rd-4th day of medication, the euphoria was less pronounced, and a general sluggishness, lethargy, and passivity had come to the fore. The sleep disturbances persisted for 2-3 nights after withdrawal of the medication: the subjects took a long time to get to sleep in the evening, were unwilling to wake up in the morning, and remained sleepy for some time.

The three individuals who were subject to physical loads (series III) showed less distinct neuropsychic changes. The symptoms of neuropsychic disorders were observed in all subjects of this group, but they did not appear during the same period, were manifested in various ways, and lasted for various lengths of time.

They appeared earliest in M. M-k (on the 14th-15th days from the start of hypodynamia) and continued in evidence for two weeks in the form of certain symptoms of emotional instability that did not reach the level of a morbid state: from time to time, he would become irritated over a trifle or evince displeasure at the tests that were being performed. The mood of K-v and V. M-k changed

toward the end of the 4th week in hypokinesia after a minor incident in the ward: in accordance with the schedule for the day, the television set was shut off in the evening, and the subjects objected to this. After this incident, V. M-k was slightly irritable for two days and complained of feeling poorly, but his behavior remained orderly. Emotional instability was more pronounced in K-v, and was registered for two weeks: he was surly when addressed and rude to the doctors and attendant personnel, threatening to quit the experiment. K-v offered as an explanation for his irritability the fact that his mother was sick.

From this point to the very end of hypodynamia, all series III subjects behaved calmly. They were for the most part in a good mood, conversed actively with one another, were polite to the doctors and attending personnel, read works of fiction, /174
watched television, and slept quietly at night. V. M-k gave a particularly good account of himself; his optimism had a favorable effect on the other subjects in the ward. At the same time, all subjects (most frequently K-v and M. M-k, less often V. M-k) reported on specific questioning during period that they were "fed up with everything," "fed up with being tested," that "there are days when my insides are in a turmoil," "even funny movies don't cheer me up," "the presence of the doctors irritates me," and "it's getting hard to take the pinpricks."

Finally, no marked disturbances of neuropsychic activity were observed throughout the entire time in hypodynamia among any of the subjects in series IV and V, who were subject to more intensive and complicated physical loads. All of them were in a good mood and took a relaxed attitude to all forms of testing, including those that caused pain and discomfort. During the day, they read fiction and technical literature, and at night they slept for 7-8 hours. Their behavior was even. During hypodynamia, two subjects (A-v and L-i) developed acute appendicitis, K-ya suffered a flareup of low-level otitis media and F-v had a vasomotor rhinitis, but the volunteers showed no pronounced psychic maladjustments as these somatic complications developed. During the last 5-7 days of hypokinesia, the subjects appeared somewhat lethargic and passive, but they registered no complaints. On release from bed confinement, they complained of pains in the muscles of their legs, but they were still in a good mood from the very first day, quiet, sociable, and active.

Thus, manifest changes in psychic state arose during hypodynamia in the series I subjects, who were strictly confined to bed, and in the individuals who received the mixed medication (series II). These disturbances were less pronounced among the volunteers who were allowed physical exertion in series III, and practically absent in series IV and V, where a more complicated composite physical load was imposed.

All of the above gives reason to assume that the very factor of forced immobility is decisive in the development of neuropsychic disorders during hypodynamia. At the same time, the appearance of these disturbances seems to depend also on the personal idiosyncrasies of the subjects. This is indicated, for example, by the fact that the depth and duration of the psychic-activity disturbances varied under identical experimental conditions; moreover, no clinically discernible psychic disturbances at all appeared in some of the subjects who did not do physical exercises (K-n in series I and G-y in series II).

STABILITY OF PSYCHIC FUNCTIONS DURING PROLONGED CONFINEMENT TO BED

/175

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ABSTRACT: Undesirable changes in the psychic functions were manifested to a lesser degree than were vegetative shifts. For the most part, the subjects retained operational efficiency and matched their original scores or even improved on them as a result of training in tests that characterize memory, the stability, distribution, and transfer of attention, sensomotor reactions, accuracy of time-interval judgment, mentation efficiency, etc. Sometimes the minor changes observed had an initial tendency toward deterioration, with a subsequent improvement of the indicators on the function-mobilization pattern, resembling the "anxiety reaction" to a state of stress. Such changes were particularly distinct during some of the periods when psychopharmaceuticals were being given. The detrimental changes were less frequent in the groups who performed physical exercises. The decrease in emotional stability and the increase in the numbers of errors can be explained by preferential weakening of the inhibitory process.

Certain authors who have performed experiments in which mobility was limited for long periods have reported lower stability of psychic functions in addition to the various physiological shifts (Dzhamgarov, Petrushevskiy, 1962; Gorbov et al., 1963; Gerd, Panferova, 1966, Zharov et al., 1967 and others).

Interest attaches to evaluation of the stability of psychic functions and, in context with this, working reliability during unusually long periods of hypodynamia, as well as tests of the effectiveness of various ways and means of maintaining this stability.

We made it our task to determine changes in certain psychic functions in an experimental study:

a) with prolonged (70-day) strict confinement to bed;

b) under the same conditions, but with periodic administration of medication consisting of amphetamine, securinine, and

caffeine;

c) under the same conditions, but with systematic physical exercising in the supine position.

EXPERIMENTAL METHOD

Before and after each experiment and, in some cases, at 10-day intervals, the subjects were tested by several procedures, which we have arbitrarily classed under the following headings: a) operational efficiency and reliability; b) emotional stability; c) specific mental processes.

Operational efficiency and reliability were investigated before and after the experiment by having the subjects perform a special set of tasks that also made it possible to evaluate visual-motor coordination and attention-distributing ability and to detect tension (Dzhamgarov, Marishchuk, Dem'yanenko, Stupin, 1964). In addition, operational reliability was also evaluated with the "Abdiv" (Marishchuk, 1964) and "Attentsiometr" (Milyaryan, 1968) machines.

Emotional stability, as the ability to maintain stable psychic functions, coordination of movements, and high working efficiency under the action of stress factors (Marishchuk, 1964, 1966), was evaluated by simulation of emotiogenic situations during the tests and by issuing special instructions for the performance of blank tests. /176

Specific mental processes were investigated in terms of performance in collective tests: memorizing and immediate repetition of words and numbers (short-term memory); solution of arithmetic problems (mental efficiency); deletion of specified symbols in tables of Landolt rings, which characterized stability of attention and the capacity of the visual analyzer (Genkin, Medvedev, Shek, 1963); number finding with transfer between red and black tables to evaluate distribution and transfer of attention (Marishchuk, Petrushevskiy, Sysoyev, 1968). We also evaluated certain individual intellectual characteristics (by the Wechsler methods and associative tests), accuracy of time-interval reproduction (4-6 sec), and sensomotor reactions using our own equipment (Platonov, 1960) and a "tremometer-coordinatiometer" (Marishchuk and Brykov, 1966). The typological peculiarities of the subjects were judged for the most part on the basis of anamnestic data on their vital indices (Il'ina, Paley, 1958; Marishchuk, Men'shikov, 1968, and by the Ayzenk method).

EXPERIMENTAL RESULTS

On testing to obtain the initial data on the typological peculiarities, all subjects were found to have nervous systems of the strong type with respect to excitation. Relative weakness of the

inhibitory process was discerned in two individuals (Ch-y and B-y). G-y showed a certain inertia of the basic nervous processes.

TABLE 1. PERFORMANCE RESULTS IN "OPERATOR-ACTIVITY" TASKS (in % of wrong operations) /177

Subject	Routine Task		Under Conditions of Stress	
	Background	After Hypodynamia	Background	After Hypodynamia
Group I				
M-s	57	56	48	51
K-n	61	52	57	52
Ch-y	54	61	67	82
K-s	52	—	51	—
Group II				
B-y	36	33	33	36
B-k	77	61	58	60
G-y	45	45	46	45
Group III				
M. M-k	46	42	38	34
V. M-k	55	50	57	58
K-v	37	44	30	60
Group IV				
A-n	77	75	67	70
F-v	63	67	57	69
L-i	59	—	55	—
Group V				
K-ya	71	—	71	—
B-v	55	61	55	65
A-v	76	74	77	82
Mean M	57.5	55.6	54.1	58.7
m	3.3	3.7	13.1	15.2

As for intellectual capacities, K-m had the lowest scores in all tests, while B-y and B-k scored highest.

Subjects Ch-y, B-y and K-ya had the low emotional-stability indicators.

No particular changes in operational efficiency were observed. On repeated testing on our apparatus, the subjects even improved their scores slightly, evidently as a result of familiarization with the tests and positive emotional excitation over the successful completion of the experiments. However, cases of poorer performance can be found when the results are evaluated individually (Table 1). Here, the number of individual wrong operations increased for B-y and K-v, coming to exceed 2-3 sigmas;

this can be interpreted as "operational malfunction," i.e., lowered operating reliability. In addition, almost half of the subjects turned in poorer times in performing the more complex tasks.

Summarizing the operator-activity tests in general terms, we can again state that the subjects remained efficient, but that their operational reliability declined slightly, with the adverse changes less conspicuous in the groups who engaged in the physical exercises.

Emotional stability was found to be more variable. As we see from Table 1, the subjects scored lower after than before the experiment in the tests performed under stress, and the performance of K-v showed a genuine deterioration under electrocutaneous stimulation (see Table 1). /178

During hypodynamia, the model used for activity under emotiogenic conditions (stress) was a number-finding problem with attention transfer to be performed under distracting conditions with the instruction: "You must do better on this problem than you did before, in spite of distractions!" It was found that even against the background of substantial familiarity with the test, the scores of some subjects (especially K-v) also deteriorated markedly during the experiment (consistent with the scores in the test performed under stress).

INVESTIGATION OF SPECIFIC MENTAL PROCESSES AND PSYCHOMOTOR FUNCTIONS

No substantial differences between the results obtained before and after hypodynamia were established on evaluation of certain intellectual properties with the Wechsler test (in which A.I. Maslovskaya assisted). The variations in the "IQ" did not exceed 2-3 units.

Nor were there any particular changes in the other tests that characterize the intellectual sphere (associative-mentation, logic, and other tests). Subject K-v again scored the lowest results, and B-k and B-v maintained the highest scores at the beginning, middle, and end of the experiment.

Likewise, the memory studies were unable to detect any general trend of the variations, and there were no particular differences between groups, although the variability of the results was quite high during hypodynamia (coefficients of variation ranging from 10 to 18). However, the number of errors in repeating words and numbers increased substantially in occasional cases (Table 2).

The variations in the memory test (as in the other tests) were sometimes especially pronounced after the subjects had

TABLE 2. MEMORIZING AND IMMEDIATE REPETITION OF WORDS AND NUMBERS (Out of 60)

Subject	Initial Data		40 days into Experiment		65 days into Experiment		During Recovery Period	
	Remembered	Errors	Remembered	Errors	Remembered	Errors	Remembered	Errors
Group II								
B-y	32	4	29	4	30	4	29	4
B-k	31	2	30	6	34	4	34	3
G-y	30	5	30	8	26	10	34	8
Group III								
M. M-k	35	3	31	4	32	4	32	3
V. M-k	34	3	36	1	33	3	33	3
K-v	30	1	39	1	28	1	28	2
Group IV								
A-n	36	0	38	0	33	2	37	0
F-v	34	3	27	3	28	7	30	3
L-i	32	4	37	1	31	3	—	—
Group V								
K-ya	39	4	37	1	39	7		
B-v	31	1	28	4	27	8	31	2
A-v	43	2	43	3	48	4	44	2
Mean M	33.9		33.7		32.4		32.2	
m	1.1		1.5		1.2		1.4	

received the medication (in group II). Once, for example, B-y remembered 12 out of 30 words and reproduced 4 incorrectly, and remembered only 5 out of 30 numbers accurately, making mistakes in 13. In the same study, B-y remembered only 10 of 30 words and made 5 mistakes. However, these shifts were brief and associated with the specific functional state of the subjects in relation to the properties of the medication. The test results would stabilize again on the next day. It is also important to note that rather distinct enhancements of short-term memory were observed at various stages of the experiment in some of the subjects; in our opinion, this was characteristic of definite phase shifts in the pattern of function mobilization under stress, e.g., in L-i and A-v (Table 2).

No particular differences were brought out among the groups on evaluation of attention stability and visual-analyzer capacity by the Landolt-ring test. Only the fluctuation of indices that is usually encountered in this test, trainability, and a slight decrease in the results at the middle of hypodynamia were noted.

In the studies of attention distribution and transfer with the red and black tables, a rise in the indices was generally observed during the experiments, chiefly as a result of training, but deterioration of scores was also observed in many cases, especially in the test with distraction.

In general, the results scored in solving arithmetic problems improved as a result of familiarization with the test. Thus, the subjects performed an average of 175 arithmetic operations correctly in a 5-minute test given during the initial examination, /180
177 after 10 days, 190 after 65 days, and 191 during the recovery period.

On evaluation of the accuracy with which time intervals were reproduced, the over-all average test results also indicated familiarization with the test, but some of the subjects showed a rather clear tendency toward poorer scores (Ch-y, B-k), and B-k and B-y also registered a noticeably larger number of premature reactions, which we attribute to weakening of the inhibitory process. Moreover, despite improvement in the average results, the number of individual grossly erroneous responses increased, with the absolute values exceeding two or three sigmas; this can be interpreted as indicating lowered operational reliability.

No substantial changes were observed on investigation of sensomotor reactions or in the tapping test.

Beginning in the 3rd or 4th week of hypodynamia, most of the subjects also showed somewhat lower visual-analyzer lability (according to the critical merging frequency of light flashes) and somewhat lower electrical excitability of the optic nerve (according to phosphene data). However, the differences were not

statistically reliable.

CONCLUSION

The investigations indicated that at the beginning of a 70-day confinement to the horizontal position, adverse changes in the stability of the psychic functions were less pronounced than the substantial shifts observed in the case of the cardiovascular system, physical strength, endurance, coordination of walking motions, etc. For the most part, the subjects remained operationally efficient, maintaining their initial scores and even improving on them through training in tests that characterize memory, the stability, distribution, and transfer of attention, sensomotor reactions, accuracy of time-interval judgment, mental efficiency, etc. The minor changes noted were sometimes in the direction of deterioration at first, but then showed an improvement of the function-mobilization type similar to the "anxiety reaction" in a state of stress.

At the same time, a certain decrease in the emotional stability of the subjects can be reported quite confidently; they made increasing numbers of mistakes that could be classified as "failures," i.e., their operational reliability had decreased. Such changes were particularly distinct at times when psychopharmaceuticals had been administered. Adverse changes were less frequent in the groups that engaged in physical exercise.

We explained the observed decrease in emotional stability /181
and the increased numbers of mistakes (which also had confirmation in behavioral reactions, e.g., increased irritability of the subjects) as due to a certain preferential weakening of the inhibitory process. This interpretation of the data is also confirmed by the fact that the speed of activity increased with the increasing error frequency in the entire series of tests. The data are consistent with results that we have obtained in the past, whose result was that many extremal loads initially tend to weaken the inhibitory process and increase the frequency of mistakes (Marishchuk, Bondarev et al., 1967). These changes also depended on the initial data characterizing level of emotional stability and, in particular, intellect. The changes were less favorable among subjects with inadequate emotional stability and low scores on tests characterizing intellect (Ch-y, B-y, G-y, K-v). Against the background of such a long experiment, these changes sometimes fluctuated along with the functional state of the subjects and the dynamics of their mental attitude toward the performance of the various tasks.

The studies also indicated a somewhat negative effect of the medication and, on the other hand, a favorable effect of physical exercises, especially autogenous conditioning, on the psychic functions and emotional state. No differences in the effects of exercises on the special treadmill and the bicycle ergometer were noted.

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INFLUENCE OF PROLONGED HYPODYNAMIA ON THE STATE OF THE VESTIBULAR ANALYZER

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ABSTRACT: The excitability of the vestibular analyzer increased in a number of cases during prolonged hypodynamia. Phasing was observed in the excitability changes. The largest changes were noted on the 7th, 10th, and 20th days of hypodynamia in individuals whose vestibular function had been found to be asymmetric before the experiment. The transition to active movement after hypodynamia was accompanied by vestibular-function disorder, with normalization not before 2-3 weeks. It may be concluded that the functions of both vestibular-analyzer receptors are disturbed during hypodynamia, but that the otolith apparatus is more strongly affected. Repeated administrations of the caloric test may be accompanied by pathological effects; it must therefore be used with great caution.

The influence of prolonged hypodynamia on vestibular-analyzer function in man has not yet been adequately studied. The domestic and foreign literature offer only occasional articles concerned with the effects of short-term hypodynamia on the function of the vestibular analyzer (Yuganov et al., 1965; Yakovleva et al., 1966, 1967; Graybiel and Clark, 1961; Brown, 1961, and others).

We investigated the influence of hypodynamia on vestibular-analyzer function in 16 male volunteers ranging in age from 21 to 23 years in five series of experiments (see Sorokin et al, this collection).

The following techniques were used in studying vestibular-analyzer function before and after hypodynamia: the Barany rotation test, in which the durations of the sensory counterrotation reaction and the post-rotation nystagmic reaction were determined;

determination of the vestibular analyzer's threshold of galvanic-current excitability;

study of the otolith reaction after V.I. Voyachek;

simple and sensitized Romberg tests;

determination of stability while standing on one leg (in series II-III).

During hypodynamia, dynamic observations were made of the otolithic deflection of the eyes when the head was turned sharply, spontaneous and fixation nystagmus, spontaneous steadying with the arms, and vertical writing. The subjective states of the subjects were also considered (dizziness, heavy-headedness, and other subjective sensations), and thresholds of sensitivity to galvanic current were determined. The OR [otolith reception] organs were examined endoscopically in each test. /183

Two series I subjects were placed on specially designed suspended cots and subjected to swinging motion throughout the day, while the other two were placed on ordinary cots.

Analysis of the results obtained for the series I subjects indicated marked changes in the individual vestibular reflexes arising during hypodynamia; these changes were manifested to varying degrees, depending on the period in hypodynamia.

During the first period (7 to 10 days), all subjects showed increased sensitivity of the vestibular analyzer to galvanic current. When the head was turned abruptly or the eyes deflected laterally to the limit, they became dizzy and slightly nauseous.

During the second period (10 to 20 days), adaptation of the vestibular analyzer to the new conditions of functioning intervened, and the deviations of the vestibular reflexes were insignificant.

During the third period (20 to 70 days), no marked shifts in vestibular reactivity were noted.

Subjects M-s and K-n, who were swung back and forth, registered complaints of nausea and dizziness after two days, and for this reason the swinging was temporarily stopped. When it was later resumed, there were, as a result of adaptation, no unpleasant sensations. However, during the night, when the cots were secured and there was no swinging motion, the subjects experienced the illusion of swinging while asleep or when their eyes were closed.

Subject K-s, who had an ordinary cot, developed acute neurotic disturbances against a background of enhanced vestibular reactivity after 21 days in hypodynamia, and he refused to continue the experiment. The other three subjects remained in the hypodynamic condition to the end of the scheduled period.

During the period of recovery after hypodynamia, the orthostatic test produced sensations of dizziness, mild nausea, trembling in the legs, and slight chills in all subjects. These sensations lasted for different times in different individuals — from 30 sec to 2 min.

After being turned from the vertical to the horizontal position, the subjects felt momentarily as though they had been stood on their heads (this sensory reaction apparently originates from the otolith receptor).

Vestibulosomatic reflexes and the body-equilibration functions were investigated at various times during the recovery period.

During the first few days after resumption of active movement, the Romberg test produced distinct tremor in the fingers, /184
and the subjects found it difficult to keep balance for 30 seconds. In the sensitized Romberg test, they kept balance for no more than 5 seconds (as against 30 seconds before hypodynamia).

The vestibular reactivity to adequate stimuli was markedly higher. It did not decrease to the initial level for 7-10 days after the resumption of active movement.

Thus, vestibular function did not normalize in the subjects during the first week after the prolonged hypodynamia; a longer time was required for this.

Two of the series I subjects were transported by airplane over a distance of about 700 km without interrupting hypodynamia. Toward the end of the flight, both developed symptoms of motion sickness (heaviness and unpleasant sensations in the head, nausea, vomiting in one subject), while vanished only after a night's sleep. Both subjects reported slight dizziness and nausea for a day after a ride on the centrifuge at the end of hypodynamia.

Prior to hypodynamia, all series I-V subjects were found to be stable to vestibular stimuli. In two series II subjects and two in series III, a more pronounced reaction to OR was observed. The same subjects showed no vegetative reaction to OR.

The series II-V subjects performed equally well in the simple Romberg test before and after hypodynamia.

In the sensitized Romberg test, three subjects from series II, two from series III, and one from series IV were found to be less stable after hypodynamia.

The times for which the subjects could stand on one leg were invariably shorter after hypodynamia, but more conspicuously among the series II and IV subjects.

The duration of the post-rotation nystagmic reaction showed no substantial change after hypodynamia in the series II-V subjects.

The sensory reaction — the sensation of turning in the opposite direction — changed in one series III subject and one series IV subject; there were no changes in the others.

The objective vestibular-function disorders that we recorded during hypodynamia were quite spotty and phased. At the 7th and 20th days in hypodynamia, we observed otolithic deflection of the eyes in response to sharp turns of the head in one series III subject and one in series IV.

Fixation nystagmus was observed in all series II subjects and one series IV subject. The galvanic-current excitability thresholds of the vestibular analyzer were higher in one series II subject (on the 9th day of hypodynamia), in one series III subject (on the 18th day), and in one in series IV.

Subjective signs of vestibular-function disturbance in the /185
form of a heavy-headed sensation appeared in all series III subjects and one series II subject at the end of the first week. On the 6th day of hypodynamia, one subject each in series II and IV reported dizziness.

Abrupt lifting of the head from the pillow produced unpleasant sensations in the head in most of the subjects, and especially in those of series II, IV, and V.

Analysis of the data obtained in series I-V indicates that changes in individual vestibular reflexes occurred while the subjects were in hypodynamia. These changes were phased. Although the disturbances to vestibular function were most conspicuous at the end of the first week in hypodynamia, there was a subsequent adaptation to them. However, reactivity of the vestibular analyzer appeared again in some of the subjects toward the beginning of the fourth week. Thereafter, and for the duration of hypodynamia, no marked changes in the vestibular reflexes were observed, except that abrupt raising of the head from the pillow, especially in the sagittal plane, would produce unpleasant sensations in most of the subjects; however, these vanished quickly.

It should be noted that the objective changes in the vestibular function were for the most part attended by subjective sensations. On comparison of the results obtained for the vestibular function in series II and III, i.e., with and without physical exercising, it was found that there were no substantial differences in the variations of the reactions registered, but that the enhancement of vestibular activity was less pronounced among the subjects who did the phsyical exercises than in those who received medication.

During the recovery after hypodynamia, all subjects reported dizziness, slight nausea, and trembling in the legs during the orthostatic test. These sensations lasted for different times in different subjects (from 20 seconds to 2 minutes).

During the first few days after resumption of active movement, series II and III subjects showed a pronounced tremor of the fingers in the Romberg test. In the simple Romberg position on the 7th day after reactivation, they maintained balance with a certain amount of strain for the same time as during the initial period. In the sensitized Romberg test, however, the series II and III subjects showed almost identical stability decreases. It would seem that the physical exercises should maintain better tone in the lower extremities, but they were of almost no help in regard to performance of this test; this suggests a high degree of complexity in the mechanism that balances the body.

Thus, the vestibular function had not yet normalized in the series II-III subjects at the end of the first week following prolonged hypodynamia. A longer time is apparently required for this recovery. /186

All of the series II-III subjects stayed with the hypodynamia experiment to its scheduled end and tolerated the airplane flight satisfactorily. Toward the end of the flight, two of the series III subjects complained of fatigue and headache, while the others came through the flight satisfactorily.

Thus, the series II-III subjects generally showed satisfactory tolerance — better tolerance than the series I subjects — to a ride (still supine) in a motor vehicle, then an airplane flight, and another motor-vehicle ride, all of which impose vestibular stimulation.

Before and during hypodynamia, the subjects of series IV-V were given the caloric test (100 ml of water at 20°C). Nystagmus was registered electrographically.

On the 33rd day in hypodynamia, subject K-ya developed acute bilateral otitis media, apparently as a result of repeated cold irrigation. Endoscopic examination showed moderate hyperemia of the tympanic membranes, with a small amount of clear mucoid effusion. The acute phase of the otitis was sluggish and went on for two weeks (under the conditions of the treatment given). The other two subjects complained of pains in their ears, and their eardrums were slightly reddened; for these reasons, the caloric test was discontinued on the 33rd day of hypodynamia.

In the case of F-v, the caloric test showed a distinct imbalance of labyrinth excitability. For example, in the second control test, infusion of water into the right and left ears produced nystagmus lasting 55 and 102 seconds, respectively; the

frequencies of the nystagmic jerks were 18 and 8, and the sensory perceptions lasted for 37 and 52 seconds.

The electronystagmogram (Fig. 1) clearly shows the asymmetry on irrigation of the right and left ears.

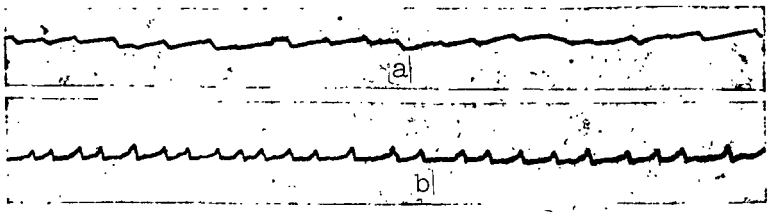

Figure 1. ENG on Irrigation of Right (a) and Left (b) Ears.

Although the difference in the nystagmus characteristics of this subject underwent subsequent changes, the asymmetry persisted (both before and after hypodynamia).

No regular changes were noted in the other series IV-V subjects in the caloric test.

In the galvanic test, most of the subjects in all series showed raised thresholds for the first ten days. Subsequently, the threshold either remained constant or became slightly lower.

Substantial deviations in the "vertical writing" test were observed at various times during hypodynamia in all series II-V subjects (on days 10-11 for three subjects, on day 18 for two, on day 23 for three, and on day 33 for one). The deviations ranged from 5.5 to 13 mm. The largest deviations coincided with the period when the imbalance of labyrinth excitability made its appearance.

Thus, the results indicate that hypodynamia causes certain /187
functional changes in the vestibular analyzer, which were not equally manifest in all subjects: the largest changes appear in those individuals who showed signs of excitability imbalance between the right and left labyrinths before hypodynamia.

Phases were observed in the vestibular-analyzer functional changes during hypodynamia in all five series: a period of enhanced excitability of the vestibular analyzer (on the 7th, 10th, 12th, and 20th days of hypodynamia) was followed by a gradual adaptation to the new function conditions; however, the adaptation was not stable, and it was sufficient to apply weak adequate stimulation (sharp turns of the head or abrupt raising of the head from the pillow) to produce symptoms of vestibular disturbances.

The changes in the vestibular function during hypodynamia were similar to those observed in patients after prolonged confinement to bed. Clinical practice has taught us how difficult the period of transition from horizontal to vertical is for patients. It appears that the vestibular-analyzer function is a factor of no small importance here.

Under the conditions of hypodynamia, the vestibular receptors do not receive the accustomed stimuli that arise under the normal conditions of vigorous motor activity in man. Long times spent in the horizontal position produce substantial changes in the conditions under which both the ampullar and otolith receptors function. It appears that the otolith receptors come under particularly unfavorable conditions during hypodynamia, since gravitational forces then act at all times only in one direction (across the body's axis). Moreover, disturbance of vestibular-analyzer function may also arise during hypodynamia as a result of hemodynamic shifts in the region of the inner ear. It is known that these factors are operating in the eteology of Meniere's syndrome and a number of other functional vestibular disturbances.

Thus, the absence of accustomed stimuli for the vestibular receptors not only disrupts their functioning, but may also have adverse effects on the interaction of afferent systems.

CONCLUSIONS /188

1. Prolonged hypodynamia influences the functional state of the vestibular analyzer.

2. In some cases, the excitability of the vestibular analyzer increases during hypodynamia.

3. Phases are observed in the excitability variations of the vestibular analyzer. The greatest functional changes are noted on the 7th, 10th, and 20th days of hypodynamia.

4. The greatest degree of vestibular-function disorder was observed in persons who had shown asymmetry of the vestibular function prior to hypodynamia.

5. The transition to active movement after hypodynamia again causes disturbance of the vestibular function; normalization takes at least 2-3 weeks.

6. Considering the nature of the sensory, animal, and vegetative reflexes, it may be concluded that the functions of both vestibular-analyzer receptors are disturbed during hypodynamia, but that the otolith apparatus is most strongly affected.

7. The caloric test, which was administered to the subjects repeatedly during hypodynamia, is not always harmless, and must

therefore be used with great caution.

8. Combined investigation, with attention to individual deviations, should be used in evaluation of vestibular-apparatus excitability during hypodynamia.

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STATE OF THE VISUAL ANALYZER DURING HYPODYNAMIA /189

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ABSTRACT: A decrease in certain visual functions and a change in the fundus picture of the eye were observed as effects of prolonged hypodynamia on the visual analyzer. Visual acuity decreased by 21% and intraocular pressure by 3 mmHg; there was a 15° loss in peripheral vision, the point of clear vision had moved out 4.5 cm, the size of the blind spot had increased by 38%, and there was a 120% increase in the time to recover visual acuity after flashing light in the eyes. Reactive vascular effects were noted on the fundus of the eye: the veins were dilated, tensed, and darker in color. The optic disk had faded. The transition to motor activity resulted in gradual recovery of the disturbed functions. However, they had not recovered fully after 20 days of observation.

In a search of the literature available to us, we were unable to find reports characterizing the state of the visual analyzer under conditions of prolonged hypodynamia.

The present paper reports a dynamic study of the state of the visual functions among 16 healthy individuals during a prolonged sojourn under the conditions of hypodynamia. Among the features of the experiment, it should be stressed that the subjects were allowed to read as much as they pleased, so that a definite visual load was provided.

The following visual functions were investigated by the standard techniques: acuity and field of vision, peripheral vision, size of blind spot, near point of clear vision, intraocular pressure, color perception; the times to recover initial acuity of vision after "blinding" with 900 nits for 3 min was also determined. In addition, the ocular fundus was studied with the ophthalmoscope.

To obtain background data, examinations were made before hypodynamia was started. Before hypodynamia, visual acuity averaged 1.25; peripheral vision extended to 62.3°, intraocular pressure averaged 20 mmHg, the near point of clear vision was at 8.5 cm, the area of the blind spot was 75 cm^2 (determined at a distance of 1 m with a 0.5 cm white object), and the recovery time

of visual acuity (used to estimate the resistance of the subjects to dazzling) was 27 seconds. The ocular fundus picture was normal for all subjects: the optic disk was pale pink with sharp boundaries, and there were no peculiarities of blood-vessel size.

Among the deviations from normal observed in the primary examination, note should be taken of a decrease in visual acuity to 0.4 (in one eye) in two subjects, Ch-y and M-s, and to 0.9 for G-y.

The next examination was made 45 days into hypodynamia. When the resulting data were compared with the results of the background study, changes were noted in the following indicators: visual acuity had decreased by an average of 21%, peripheral vision was 11° narrower, intraocular pressure was down 3 mmHg, and the near point of clear vision was consistently more distant, by an average of 3.5 cm over all subjects.

On a repeated examination on the 67th day of hypodynamia, the narrowing of the visual field was 15°, and the near point of clear vision had moved out by an average of 12.5 cm. On the average for all subjects, hypodynamia lasted 70 days.

On the second day out of bed, the subjects' visual acuity /190
remained down (by 21%). By comparison with the background data, the blind spot had enlarged by an average of 38%, and the time to recover visual acuity had also increased 120%.

On ophthalmoscopy, the fundus of the eye showed fading of the optic disk, and its temporal boundary was somewhat indistinct. The veins had enlarged, were distended and darker in color (by comparison with the background data). Moderate enlargement of the retinal artery was observed among the series I subjects. When the subjects were inspected on the 20th day after hypodynamia, visual acuity had still not returned to the initial values. The blind spot was smaller, but had not reached its original size (it was 19% larger than the background figures); the time to recover visual acuity was shorter, but still 50% longer than in the background study. Ophthalmoscopy showed that the reactive vascular effects had receded: the arteries were of normal size, the veins only slightly enlarged, and the optic disk was pink, with sharp outlines. There had been no changes in field and color perception under the influence of hypodynamia.

Literature sources refer to a detrimental effect of weightlessness and hypodynamia on stability to acceleration. To determine acceleration stability, therefore, we tested the subjects on a centrifuge before and after the extended hypodynamia. Before hypodynamia, the fundus of the eye showed enlarged veins and arteries, the background of the retina was red, and the boundaries of the optic disk were sharp after the subjects had sustained the maximum permissible accelerations.

The reactive vascular changes were more strongly pronounced in the series I subjects on the 70th day of hypodynamia following maximum transverse acceleration; the minute vessels on the optic disk were visible. The retinal background was bright red.

Among the series II subjects, who had received internal medication, we noted sharp constriction of the arteries, while the veins remained at normal size. The arteries of the fundus were of normal size 30 minutes after acceleration, the veins were slightly enlarged, and the background of the retina was pink.

The reactive vascular effects were less pronounced in the series III subjects: the arteries were slightly enlarged, the veins moderately dilated and tensed.

The reactive vascular changes in the fundus of the eye were mild in series IV and V: the arteries were dilated slightly and the veins moderately.

Thus, it was established by the study that prolonged limitation of motor activity results in certain changes in the visual functions, but that they are not so profound as to disable the visual apparatus or have any perceptible influence on the visual performance of an operator. /191

Resumption of motor activity resulted in a progressive recovery of the disturbed functions. However, they had not recovered to their initial level according to observations made up to 20 days after hypodynamia.

It follows from analysis of the data obtained that the change in the visual functions (lowered visual acuity, restriction of peripheral vision, lower intraocular pressure, increased blind-spot area, lower stability to dazzling) can obviously be explained by disturbances to the nutrition and oxygenation of the retinal nerve cells. The retinal hypoxia results from disturbance to blood circulation in the basin of the internal carotid artery. The dilation of the retinal veins indicates stagnation effects in the venous system of the retinal circulation; the dilation of the retinal arteries indicates lowered tone of the vessels and a decrease in circulating blood mass. Fading of the optic disk is evidently associated with deficient nutrition of the nerve fibers because of the hemodynamic disturbances.

In view of the common phylogenetic origin of the eye, the brain, and their vessels, inferences as to the blood circulation in the brain can be drawn from the retinal circulation. All changes observed on the ocular fundus reflect intracranial vascular shifts (Shershevskaya, 1955; Kedrov, Naumenko, 1954, and others).

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PHYSICAL CONDITIONING FOR MAN UNDER CONDITIONS OF PROLONGED HYPODYNAMIA

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ABSTRACT: Under conditions of artificially suppressed physical activity and prolonged confinement to the horizontal position (70 days), use of specific sets of physical exercises reduces hypodynamic shifts, especially as regards the strength of various muscle groups, static endurance, the coordination habits of walking and psychomotor functions. Exercising on a "treadmill" appliance has advantages over the bicycle ergometer as regards its prophylactic effect, methodologically, and from the standpoint of the emotional effect of the exercises.

In the view of many investigators, the orthostatic instability exhibited by cosmonauts immediately after flights resulted from dehydration of the organism because of deficient performance of the spacecraft temperature-control systems (David, 1964). Others (Lamb et al., 1964) also conclude that weightlessness has no decisive importance for hemodynamics, but link the orthostatic instability to reduced motor activity (the effect of hypokinesia), which causes deconditioning of the cardiovascular and muscular systems. /192

One of the important factors contributing to the prevention of ill effects under the conditions of prolonged weightlessness or its simulation is physical exercising (Bazhanov, Chudinov, 1965). However, sensible determination of the expedient volume and intensity of the physical load, its distribution over the days of the conditioning cycle, and the selection of rational physical-conditioning facilities for use on flights of various durations are still in the stage of scientific trial-and-error.

The present study made provision for determination of changes in physical-fitness indicators and in the physical condition of humans under the influence of prolonged (70 days) hypodynamia in the supine position without and with use of various sets of physical exercises. Here, the physical conditioning solved the following problems:

– preservation of orthostatic stability and stability to g-forces after prolonged enforcement of a hypodynamic regimen;

– prevention of abnormalities in body composition and bone structure and other negative consequences of prolonged restriction to the supine position;

– maintenance of muscular strength and endurance under dynamic and static physical loads; preservation of movement coordination (especially in walking and running), quickness of actions, attention, and other psychophysical properties;

– securing a general tonic effect on the nervous, cardiovascular, digestive, and other systems of the organism.

METHOD

Fifteen subjects, ranging in age from 21 to 23 years and suitable for flight service with no restrictions participated in the studies.

The studies were carried out in three steps:

step 1: three subjects spent 70 days strictly confined to bed;

step 2: three subjects did special physical exercises and three received medication;

step 3: three subjects did a set of physical exercises using a stationary "treadmill" appliance, and three did a similar set of physical exercises using a bicycle ergometer.

Physical exercise was scheduled as follows: /193

– morning calisthenics (15-20 minutes);

– composite conditioning (30 minutes) for 1.5-2 hours before dinner;

– conditioning activities (45 minutes) during the evening;

– evening "walks" (15-20 minutes) in the form of light exercises for 1 hour 45 minutes before retiring.

Setting-up exercises. Here the aim was to invigorate the organism quickly and exert a general tonic effect on the nervous, cardiovascular, digestive, and other systems of the organism. Setting-up included exercises of volition, exercises with spring appliances, contracting and relaxing muscles at will, and breathing exercises. Here, pulmonary ventilation increased by an average factor of two by comparison with initial data, increasing to 17 liters/minute during the performance of certain exercises. Pulse rate increased by 15-30 beats/min. The concluding part of

the morning calisthenics normalized respiration and pulse; after their completion, the subjects' pulmonary ventilation showed practically no differences from the original level.

Composite conditioning. The objectives were to maintain fitness and reactivity of the cardiovascular system, to prevent shifts in body composition and bone structure, to tone the organism up generally, and to maintain stability of the psychic functions. This conditioning included exercises of volition, exercises with spring fixtures and tennis balls, exercises in which individual muscle groups were stressed and relaxed at will, general static tensioning, and breathing exercises.

During performance of some of these exercises, respiratory frequency reached 18-20 per minute. Some of the exercises were performed during brief periods when the breath was held. Pulmonary ventilation averaged 11.7 liters/min over the 30 minutes of composite conditioning. The concluding exercises normalized respiration fully. During the recovery period, pulmonary ventilation dropped to 4.5 liters/min. During certain exercises, pulse rate rose by 20-40 beats/min. The return to the initial level took 3-5 minutes after the relaxing and breathing exercises.

The conditioning activities were constructed around a cycle consisting of three groups of exercises (three assignments), which were repeated by turns twice a week (the subjects rested on the seventh day, with only the setting-up exercises and the evening "walk"). Each of the three assignments was oriented preferentially to solution of specific problems.

First assignment. Here the preferential orientation was preservation of orthostatic stability and quickness and strength data. The loads were maximal and submaximal, with an energy expenditure of 200-220 calories. The work rate ranged up to 1500 kg-m/min and higher.

Conditioning procedures: /194

- loosening-up exercises, simulation of walking and slow running, breathing exercises;

- exercises with soft spring appliances, with a progressive increase in load;

- exercises on the "treadmill" or bicycle ergometer: walking, jogging (or pedalling at medium speed), running (pedalling) at maximum speed with alternating repetitions. Further, the simulation of impact load factors (on the "treadmill" only);

- exercises with contraction and relaxation of muscles at will, deep-breathing exercises, static tensioning of the arm and torso muscles with spring fixtures and tennis balls, relaxation

and breathing exercises.

Second assignment. Preferential orientation: to preserve orthostatic stability and general and static endurance. Load volume was high and intensity low; calorie expenditure 200-250 calories, work rate 200-1000 kg-m/min.

The training procedures were the same as in the first assignment. Walking and running (or pedalling) were done at average speed by the cyclic method, and prolonged static loads were imposed by the use of stiff spring appliances.

Third assignment. Preferential orientation: maintenance of orthostatic stability, general level of movement coordination (especially in walking and running), quickness of movements and attention; regulation of emotional states. Medium over-all volume of load at medium or low intensity, energy expenditure 150-180 calories, work rate 200-500 kg-m/min.

Conditioning procedures:

- loosening-up exercises and exercises with soft spring appliances, as in the first assignment;

- exercises on the "treadmill": walking, slow and medium-speed running with the treadmill set and the body turned to various angles; jumping and squatting on one or both legs, simulation of shock load factors;

- bicycle-ergometer exercises: pedalling at various speeds;

- exercises for coordination and precision of movements, quickness of movements, attention;

- exercises in volitional relaxation of muscles, breathing exercises, exercises designed to regulate emotional reactions.

During such conditioning-activity exercises as the "chest press," "pumping," slow walking, and others, respiratory rate varied from 16 to 20 per minute, while pulse frequency ranged from 88 to 110 beats/min. The depth of respiration reached 2.5-3 liters during running (or pedalling), pulmonary ventilation was 54 liters/min, and the pulse frequency from 96 to 150 beats/min. The highest respiratory frequency (up to 24 cycles per minute) was noted during accelerating runs (pedalling) at pulse rates up to 200 beats/min. The concluding exercises of the activity usually normalized external respiration. During the recovery, immediately after completion of the activities, pulmonary ventilation stood at about 4.5 liters/min. Individual differences were manifested in the recovery of pulse rate and blood pressure. /195

The evening "walk" was performed with light exercises and autogenous conditioning. During the process of volitional relaxation, pulse frequency usually slackened to 54-64 beats/min and respiration to 7-8 cycles per minute.

The structural complexity of the series of physical exercises, the combination of cyclic and acyclic forms of motion, the performance of a series of exercises with brief holding of the breath, and the combination of dynamic and static exertion required a certain conditioning period for development of a respiratory rhythm appropriate to the structure of the motor events and the work of the motor apparatus.

EXPERIMENTAL RESULTS

The results obtained for all subjects on determination of their physical fitness conformed to the average characteristic for the corresponding segment of their age group.

Their visual-motor coordination was also at the "good" and "satisfactory" levels. Subject Ch-y was found to be quite tense in the first step of the investigation, K-v and B-y in the second step, and K-ya in the third. All subjects were rated as having the strong type of nervous system on the basis of the distinctness with which excitation was registered. A certain weakness of the inhibitory process was discerned in B-y, K-v, and K-ya.

The 70-day confinement to bed had considerable influence on the physical-fitness level of the subjects.

In the first step of the study, i.e., that in which physical exercises were not used, all three of the subjects (K-n, M-s, and Ch-y) turned in shorter static-exertion times: 49 instead of 63 seconds for K-n, 27 instead of 66 for M-s, and 37 instead of 83 for Ch-y. This indicator did not change when physical exercises were employed (steps 2 and 3).

On the second day after hypodynamia (step 1 of the study), all of the subjects were unable to hold a squatting position on the floor. Not until the 6th day did K-n perform this exercise, with a 16-second time (as against the original 74 seconds), while M-s held the position for 24 seconds (against an initial 91 seconds).

None of the subjects could move about independently immediately after step 1 of hypodynamia. /196

The changes in the strength and static endurance of the muscles, which were determined with a "polydynamometer," are especially indicative. By way of example, Tables 1 and 2 present data for subject Ch-y.

TABLE 1. CHANGES IN STATIC ENDURANCE OF SPECIFIC MUSCLE GROUPS (in seconds) AFTER HYPODYNAMIA

Muscle group	Initial level	Day of recovery		
		2nd	6th	11th
Flexors of torso	67	0	16	27
Extensors of torso	130	0	58	105
Extensors of legs	140	0	63	104

TABLE 2. VARIATION OF RELATIVE STRENGTH OF SPECIFIC MUSCLE GROUPS AND RECOVERY PERIOD AFTER HYPODYNAMIA

Muscle group		Initial level	Day of recovery		
			2nd	6th	11th
Forearm	Flexors	0.72	0.54	0.75	—
	Extensors	0.55	0.40	0.48	0.57
Upper arm	Flexors	0.54	0.37	0.57	—
	Extensors	0.76	0.57	0.67	0.78
Torso	Flexors	0.82	0.43	0.74	0.83
	Extensors	1.68	1.02	1.71	—
Foot	Flexors	2.45	1.05	1.56	1.76
	Extensors	0.63	0.40	0.48	0.56
Lower leg	Flexors	0.47	0.28	0.34	0.40
	Extensors	0.85	0.57	0.70	0.71
Thigh	Flexors	0.81	0.62	0.81	—
	Extensors	1.98	1.05	1.77	0.76

As we see from the data in Tables 1 and 2, hypodynamia had an especially marked effect on the functional state of the torso muscles and the extensors of the legs. The strength of the muscles of the upper extremities changed to a much lesser degree, with complete recovery noted by the 6th day after hypodynamia, while the strength indicators for the leg muscles (except for the flexors of the thigh) did not reach the initial level even by the 11th day of the recovery period. A particularly great loss of strength, together with prolongation of the latent period and the motor component of the motor reaction, were observed in the muscles that accomplish movements of the foot. /197

Analysis of the changes in the motor reactions of various muscle groups under the influence of hypodynamia indicated that the changes observed in the speed of specific movements (the motor component) are more stable than those observed in the latent period. In all cases (except for flexing of the knee), the individual-movement times were longer. These changes were

TABLE 3. CHANGE IN ABSOLUTE STRENGTH OF SPECIFIC MUSCLE GROUPS AFTER HYPODYNAMIA WITH REFERENCE TO INITIAL LEVEL (in %)

	Group on Treadmill		Group on Bicycle Ergometer	
	Flexors	Extensors	Flexors	Extensors
Forearm	+3.5	0	+2.5	-1.0
Upper arm	+1.0	+1.5	+1.5	-0.5
Foot	-6.0	—	-16.0	—
Lower leg	+3.0	-6	+1.0	-11.0
Thigh	+1.0	-6	+2.5	-13.5

statistically reliable for six days of the recovery period (P > > 95%).

In the 2nd and 3rd steps of the study, in which the subjects performed physical exercises, the detrimental changes were considerably smaller, and certain groups of muscles were even found to have increased in strength. Here, the disturbances to locomotor coordination and the strength loss in the extensors of the thigh and lower leg and the flexors of the foot were smaller among the subjects who exercised on the treadmill than among those who used the bicycle ergometer (Table 3).

Analysis of the results led to correction of the conditioning procedure with the object of increasing the load and variety of exercises with a view to the antigravitational musculature (the extensors of the torso, thigh, and lower leg and the flexors of the foot). Basically, however, the prolonged-hypodynamia experiments indicated the high effectiveness of the physical-exercise combinations selected in maintaining muscular strength and static endurance. /198

The functional-test results also indicate a favorable effect of the specific physical exercises on the subjects' organism. In contrast to the group I subjects (strict confinement to bed), the individuals who engaged in the various physical-exercise programs produced results in the various tests — breath-holding, 20 squat jumps, Serkin test, step test — that indicated smaller changes in the functional state of the organism after hypodynamia. Thus, the subjects who had been strictly confined to bed were incapable of even the light exertion required for 20 situps until the 11th day after termination of the experiment, while the subjects who had received physical conditioning passed even the functional step test quite easily. Further, to evaluate the physical fitness of the subjects in steps 2 and 3 who had undergone physical conditioning during hypodynamia, special functional tests were given them at the end of the 2nd week, at the middle, and at the end of the experiment; these consisted in continuous pedalling of the bicycle ergometer at 75 rpm for 20 minutes, under a load of up to

1000 kg-m/min (200 kg-m/min for 2 minutes, 500 for 3 minutes, and 1000 for 15 minutes), or in steady running on the treadmill at a rate of 3.5 m/sec. The test was terminated when pulse frequency rose above 180 beats/min.

All of the subjects passed this test both at the middle and at the end of hypodynamia, except for the single case of subject M-k at the middle of step 2 of the study. It is interesting to note that the subjects in a similar American experiment usually broke off the same test after as few as 7-11 minutes (Miller et al., 1965).

Consequently, use of specific physical exercises in the hypodynamic regimen may act as a preventive, improving the function of the cardiovascular system directly during hypodynamia and preparing the subjects for the transition to vigorous motor activity under ordinary earthbound conditions.

At the same time, it should be noted that use of physical exercises in the above studies did not altogether solve the problem of maintaining the initial functional state of the circulatory apparatus, as confirmed by the rising tachycardia after hypodynamia and the decrease in the maximum arterial-pressure level. This is apparently due to certain deficiencies of the method.

CONCLUSION /199

It was found as a result of the studies that definite changes took place in the physical condition of the subjects under the conditions of artificial restriction of motor activity and prolonged confinement to the supine position, taking the form of deteriorated functional condition of the organism as a whole and, in particular, of the cardiovascular system and supporting-motor apparatus. After 70 days of the hypodynamic regimen, the subjects who did not engage in physical exercises were unable to move about by themselves. Where physical exercises were performed, all of these changes, and primarily that in the physical state of the subjects, were much less pronounced, especially as regards retention of the strength of various muscle groups, static endurance, preservation of locomotor coordination habits and various psychomotor functions. The cardiovascular systems of the subjects remained more efficient, and the effects of vascular insufficiency were less pronounced on transition from the horizontal to the vertical position and on transition from exertion to rest and rest to exertion. Emotional stability also fared better, as did efficiency under emotional stress and the sthenic emotional state.

No marked differences in either the psychomotor functions or the stability of the psychic functions were observed between the groups of subjects who exercised on the treadmill and on the bicycle ergometer, although group 1 had certain advantages as regards physical condition and preservation of walking coordination

habits. In addition, the "treadmill" appliance scores better than the bicycle ergometer both methodologically and in the sense of emotional attractiveness of the exercises.

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OCCLUSION CONDITIONING UNDER THE CONDITIONS OF PROLONGED HYPODYNAMIA

/200

V.G. Voloshin, I.D. Pestov, and B.F. Asyamolov

ABSTRACT: The paper examines a technique in which inflatable thigh cuffs are applied as a measure against the unfavorable effects of prolonged hypodynamia on the cardiovascular system. The operating principle of a machine that automatically maintains a specified occlusion-conditioning regime is described. The results of completed tests are presented and the prophylactic procedure in question is evaluated.

The theoretical foundations of the prophylactic use of devices that simulate the hydrostatic pressure of the blood under conditions of weightlessness were laid in the work of Henry et al. (1956) and Gauer et al. (1965), who showed that a drop in hydrostatic pressure results in disturbances to water-salt metabolism. Graveline (1962) was the first to use inflatable (occlusion) cuffs on the extremities to prevent these shifts; they functioned to impede the return of venous blood to the heart and thereby simulated the action of a hydrostatic blood pressure. This principle was subsequently used by other authors in experiments to simulate weightlessness (Miller et al., 1965; Stevens, 1966; Vogt, 1965, 1966, 1967a, 1967b; Buyanov et al., 1966). It was found that use of various versions of occlusion conditioning under these conditions helps prevent plasma loss and maintain vascular tonus, although the data obtained on its influence on orthostatic stability have been contradictory.

The authors of the present report also tested the occulsion conditioning principle in 18-hour water-immersion experiments. It was found that if the pressure in cuffs applied to the upper third of the thigh was raised periodically to 60-70 mmHg (pressure for 1 minute, followed by 1 minute of rest) over 8 hours during the experiment, the subjects showed improved stability in the orthostatic tests.

It was also noted that the prophylactic effect depended on certain features of the occlusion-conditioning regimen. It declined markedly for longer pauses between the periods of pressure elevation in the cuffs and when higher pressures were used. This circumstance indicates that the principle, even though there is

quite good theoretical justification for it, nevertheless requires thorough practical testing, including proper selection of the conditions with which it is applied. The lack of success of American astronauts in the use of inflatable thigh cuffs (Dietlein, Judy, 1966; Taylor et al., 1966; Berry, Catterson, 1967, Vinograd, 1967) are evidently no cause for discouragement, since the possibilities for optimization of the occlusion-conditioning regimen are far from exhausted. Although there is now a distinct tendency to develop new methods of simulating hydrostatic blood pressure under /201
conditions of weightlessness, such as a negative pressure on the lower half of the body (Stevens et al., 1966; M. McCally et al., 1966) and breathing under excess pressure (Hunt, 1967), the occlusion-conditioning technique cannot be regarded as out of the running. One of the versions of this method was tested on the series IV and V subjects (6 individuals in all) of the present investigation during the 70 days of hypodynamia.

METHOD

Occlusion conditioning was applied with the aid of a specially developed automatic machine, a block diagram of which appears in Fig. 1.

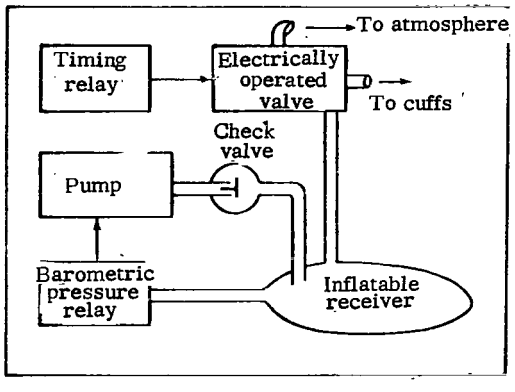

Figure 1. Block Diagram of Machine for Pressurizing Cuffs. Explanation in Text.

The high-output electrically /202
driven pump, operating through a check valve, inflates the elastic receiver to a definite pressure, to which the experimentor has set the barometric pressure relay. The relay switches off the pump when the desired pressure has been reached. The inflation schedule is set on a timed relay, which issues commands to operate an electromagnetic valve. At the start of inflation, when the valve has opened communication between the cuffs and the receiver, the pressure in the latter drops, the pressure relay operates and issues a command to the pump, which starts and maintains the proper pressure in the system. After the preset time, the electromagnetic valve disconnects the cuffs from the system and opens them to the atmosphere, so that the pressure in the cuffs drops to normal. The pump output, the capacity of the receiver, and adequate flow sections of the air lines ensured quick changing of the pressures in six cuffs simultaneously.

The subjects of experimental series IV and V were conditioned on the schedule that had been used previously in the 18-hour immersion experiments. The thigh cuffs were pressurized to 70 mmHg

and this pressure was maintained for 1 min, at which point the air was bled from the cuffs. There was a 1-minute pause before the next pressure elevation.

Since there was no previous experience in the use of occlusion conditioning in such long experiments, it was necessary to arrive at a rational regimen for applying it. Theoretically, it might have been possible to use a set of combinations whose two extremes would be daily conditioning and conditioning only in the concluding stage of the experiment. In the version that we selected, it was applied in the 4th, 7th, and 10 weeks of the experiment and thus covered both the middle and end of the period in hypodynamia. During each one-week cycle, the occlusion cuffs were applied by turns to the subjects of each group (every other day) for 3 hours in the morning, afternoon, and evening. Thus, each subject received occlusion conditioning on 4 days per cycle or on 12 days over the course of the experiment (a total of 108 hours). The final spin on the centrifuge preceded the last conditioning session. /202

We should note that occlusion conditioning was only one element in the over-all complex of prophylactic measures taken in the last two experimental series, and its effectiveness can be judged only by comparing the resulting data with the results for the first three series, in which the cuffs were not used. Comparison of the results from series III, where the subjects did the same physical exercises as those of series IV and V, is particularly appropriate.

For comparison, we used data published in this collection by other authors, with the accompanying literature references, and the results of our own observations.

Since occlusion conditioning is, in its very conception, aimed primarily at maintaining the organism's stability to gravity, the greatest interest attaches to the results of study of orthostatic stability and tolerance of transverse g's. The methods used in these studies are described in the appropriate articles of this collection. It was also felt necessary to evaluate certain direct effects of occlusion conditioning, and, in particular, data on the state of the elastic properties of the blood vessels in the lower extremities. For this purpose, we took plethysmograms of the subjects' lower legs during orthostatic tests and with measured impediments to the venous return flow (Arinchin, 1967). The volume changes of the lower leg were registered over 5 minutes as the pressure in the thigh cuff was raised in steps from 40 to 80 mmHg. The largest value of these changes characterized the extensibility of the veins. The completeness of recovery of the lower leg's initial volume after release of the pressure from the thigh cuff was interpreted as an index to the contractility of the veins. /203

RESULTS

Data from general clinical observations do not yield any definite judgment as to the advantages of the prophylactic complex, which included occlusion conditioning as a component element. We can only refer to the opinion advanced by V.P. Bogachenko (see this collection), who found that the state of psychic activity was least disturbed in the subjects of series IV and V. Apart from this, our attention is drawn to the fact that stability to the transverse g's not only had not decreased, but, to the contrary, had increased in these groups after hypodynamia, according to A.R. Kotovskaya, R.A. Vartbaronov, and S.F. Simpura (see this collection). This is essentially the most basic point in favor of occlusion cuffs as a prophylactic measure under the conditions of prolonged hypodynamia. As concerns the reactions of the subjects to the orthostatic test, the data cited in this collection (see Pestov et al., this collection) do not permit the conclusion that occlusion conditioning was helpful. There appears to be more justification for the contrary judgment. While the shifts in orthostatic stability were smaller in series III, whose subjects performed a set of physical exercises during their stay in bed, than in the preceding series, the combination of physical and occlusion conditioning (series IV and V) again resulted in a decrease in orthostatic stability. It may be, of course, that the occlusion-cuff conditioning is not alone at fault here, although there are certain reasons for drawing this conclusion. Some of them proceed from the results of study of the elastoplastic properties of blood vessels in the lower extremities. The table presents averaged data on the extensibility and contractility of the veins of the lower leg in a functional test with measured restriction of the venous flow in subjects who had not received occlusion training (series I-III) and those who used the occlusion cuffs.

The fact that occlusion conditioning prevented loss of elastic properties of the vessels in the lower extremities to a substantial degree, while it appeared distinctly in the series I, II, /204
and III subjects during hypodynamia, is quite convincing. It appears that this can be counted as a positive effect in many respects. However, from the standpoint of the genesis of orthostatic disturbances, high extensibility of the veins in response to an increase in intravenous pressure is an unfavorable reaction, since it predisposes to depoting of a relatively larger amount of venous blood in the lower half of the body. This is essentially confirmed by the results of orthostatic plethysmometry of the lower legs. It was found that the 38% increase in the volume of the lower leg in the orthostatic test after hypodynamia among the series IV and V subjects exceeded the corresponding indicator in the series I, II, and III subjects (1.2 ml/100 cm^3 of tissue and 0.87 ml/100 cm^3 of tissue, respectively), although they had been practically the same before hypodynamia (1.55 and 1.56 ml/100 cm^3 of tissue). It is also known that wearing of an anti-g suit or stretch fabrics in orthostatic tests gives a substantial

TABLE. EXTENSIBILITY (in ml/100 cm^3 of tissue) AND CONTRACTILITY (% recovery of initial volume) INDICES OF LOWER-LEG VESSELS DURING OCCLUSION PLETHYSMOMETRY

Conditions	Without Occlusion Conditioning (10 Subjects)		With Occlusion Conditioning (6 Subjects)	
	Extensibility, $\bar{X} \pm m$	Contractility, %	Extensibility $\bar{X} \pm m$	Contractility, %
Before hypodynamia	1.36±0.057	104	1.25±0.027	92
40th day of hypodynamia	0.95±0.067	74	1.19±0.107	88
60th day of hypodynamia	0.95±0.079	85	1.19±0.102	104
One month after hypodynamia	1.36±0.17	101	1.37±0.097	104

improvement in orthostatic stability after simulated-weightlessness experiments (Miller et al., 1956, Vogt, Johnson, 1967).

In this connection, the development of a certain rigidity of the veins under the conditions of prolonged bed confinement that was noted in the series I, II, and III subjects can be regarded as a favorable reaction from the standpoint of tolerance to orthostatic disturbances. And even though this reaction did not by itself prevent orthostatic collapse in the series I (control) subjects, the medication (series II) and especially the physical exercises (series III) improved orthostatic stability to some degree with it as a background. On the other hand, maintenance of the original extensibility of the veins of the legs might have caused the more pronounced orthostatic disturbances in /205
the series IV and V subjects, despite the use of physical-conditioning procedures and prophylactic medication.

In long experiments, the inflatable thigh cuffs, which were effective under the conditions of short immersion experiments, would appear to have their principal influence on the elastic properties of the veins and to have less effect on the neurohumoral regulation mechanism of blood circulation with redistribution of the blood toward the lower half of the body. Since this mechanism is not limiting under the action of transverse g's, only the positive influence of the entire complex of prophylactic measures taken in series IV and V was observed in the centrifuge studies (see Kotovskaya et al., this collection).

It must be assumed that further progress in the development of a method for simulating blood hydrostatic pressure in weightlessness will consist in the development of technical facilities and regimens capable of securing better redistribution of the blood to the lower half of the body than was obtained under the

conditions that we used. This would also provide a more harmonious conditioning action on the central and peripheral function-regulating mechanisms both under the action of g-forces and in orthostasis.

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RESULTS FROM USE OF MEDICATION IN INDIVIDUALS SUBJECT TO PROLONGED HYPOKINESIA

P.V. Vasil'yev and B.Yu. Lapinskaya

ABSTRACT: The influence of prolonged hypokinesia on the reactivity of the organism with respect to a combination of medications (amphetamine, securinine, caffeine) and the possibility of improving human tolerance to orthostatic loads and the action of transverse g-forces with the aid of these drugs were studied in experiments in which 11 subjects participated. It was established that the action of the medication changed under hypodynamia: in most cases, the effect was weaker, and inversion occurred in a number of observations. As a rule, tolerance of orthostatic loading and g-forces increased following administration of the above agents, especially when they were given to individuals who performed a set of physical exercises. In all cases, the decrease or increase in the subjects' stability after hypodynamia was arrived at with considerably greater stressing of the organism's functional systems than was observed before hypokinesia.

The results of observations made by a number of authors have indicated that human endurance of physical loads and orthostatic stability are lower after strict confinement to bed for long periods of immersion in water (Graybiel and Clark, 1960, 1961; Vanyushina, 1963; Miller et al., 1964, 1965; Lamb et al., 1964; Kotovskaya et al., 1965; Gauer et al., 1965, and others). The basic factors lowering the organism's tolerance of physical stresses and its orthostatic stability during prolonged hypodynamia are metabolic disturbances, decreases in muscle and vascular tone, and reduced plasma volume, circulating blood mass, systolic ejection, and circulation unit volume (Deitrick, 1948; Dick, 1966, Gaume and Kuchnegger, 1963; Taylor et al., 1945, 1949; Graveline, Barnard, 1961, Graveline, 1961; Miller et al., 1964, Gauer et al., 1965, Myasnikov et al., 1965; Buyanov, Beregovkin and Pisarenko, 1967, and others).

For prevention of the hypodynamic syndrome, a number of authors have suggested physical conditioning or a combination of physical exercises with periodic compression of the extremities by means of special inflatable cuffs. It is also possible to use

drugs that stimulate the compensatory-adaptive reactions of the organism to prevent hemodynamic disturbances during hypodynamia.

The observations of Gauer (1965) indicated that under the conditions of an eight-hour immersion, small doses of vasopressin prevent changes in circulating blood volume and improve orthostatic stability.

Stevens et al. (1966) used 9-alpha-fluorohydrocortisone for this purpose; it restored circulating blood mass but did not prevent orthostatic disturbances.

Strychnine, adrenalin, noradrenalin, amphetamine, Phenatin, /207
ephedrine, caffeine, Corazol, strophanthin, nitroglycerin, Dibazol, chloral hydrate, and Pentothal sodium have been used in animal experiments to improve g-force tolerance (Parin, Vasil'yev, and Belay, 1964; Belay, Vasil'yev, Kolchin, and Maslyanenko, 1964; Vasil'yev and Belay, 1965, and others). The combined use of strychnine, caffeine, and amphetamine was found to be most effective in the sense of improving stability to g-forces after hypodynamia (Vasil'yev and Kotovskaya, 1965).

The data cited above served as a basis for a study of the effects of certain drugs that stimulate the central nervous system and blood circulation on hemodynamics, orthostatic stability, and resistance to g-forces during prolonged hypodynamia.

EXPERIMENTAL METHOD

Experiments were carried out in experimental series 1, 2, 4, and 5. Eleven subjects were under observation. Each subject was assigned to one of four groups. The first, control group of subjects was placed under conditions of strict hypodynamia with no preventive measures. The second group consisted of three men who were also strictly confined to bed, but who received the medication periodically in four-day cycles. Four men each were observed in series IV and V; during hypodynamia, these subjects engaged periodically in a planned physical-conditioning program in the horizontal position, and two of them also received occlusion conditioning. Under basal-metabolism conditions, all subjects received a single dose of the combined medication, which consisted of amphetamine, caffeine and securinine. Tachyoscillograms and sphygmograms were recorded by N.N. Savitskiy's method before peroral administration of the medication and 30, 60, 120, and 180 minutes afterward. These studies were carried out during the initial period, during hypodynamia on the 15th and 53rd days in series II and the 67th day in series IV and V, and on the 16th day of the recovery period. The passive orthostatic test with a 75° inclination angle was used in the 9th week of hypodynamia to evaluate the functional state of the cardiovascular system. All series II, IV, and V subjects received the medication one hour before the orthostatic test. The tachyoscillograms and sphygmograms

were registered before the orthostatic test, after 1, 5, and 10 minutes in the vertical position, and 1, 5, and 10 minutes after the return to horizontal.

The following indicators were analyzed: the minimum (Mn), /208
average dynamic (Av), lateral (Lt), maximum (Mx), and pulse (Pp) pressures; heart stroke and minute volumes; specific peripheral resistance (Wf) and (Wr), propagation velocity of pulse wave through blood vessels of the elastic (Ve) and muscular (Vm) types.

EXPERIMENTAL RESULTS

The hemodynamic changes one hour after administration of the medication took the same direction in the initial period in the series II, IV, and V subjects.

TABLE 1. CHANGES IN ARTERIAL-PRESSURE INDICATORS AFTER ADMINISTRATION OF MEDICATION

Statistical indicator	Initial period (7 observations)				Recovery period (5 observations)	
	Av	Lt	Mx	Pp	Av	Mx
$M_2 - M_1$	7	11,2	15,4	6,7	7,4	11,2
m	1,8	3,5	3,4	2,6	1,2	4
t	~4	3,2	4,5	2,5	6	2,8
P	<0,01	<0,02	<0,01	<0,05	<0,01	<0,05

The arterial pressures showed a distinct increase in the average-dynamic, lateral, maximum, and pulse values. These changes in arterial pressure were statistically reliable (Table 1). At the same time, the action of the drugs was accompanied by an increase in the heart stroke and minute volumes. However, only the increase in stroke volume was statistically reliable. The rate of pulse-wave propagation through vessels of the muscular type increased by 25-50 cm/sec. The changes in vascular tonus, which showed a tendency to increase, were statistically unreliable.

Under the influence of the medication that we used, the actual peripheral resistance dropped slightly with the increase in blood minute volume. However, the dilation of the precapillary bed nevertheless tended to increase circulation minute volume, with the result that the average dynamic pressure rose.

During hypodynamia, the hemodynamic shifts in response to the medication differed from the data of the initial period, both /209
qualitatively and quantitatively. Analysis of the individual observations indicated that under the influence of the medication,

a given subject would, as a rule, show variations of the hemodynamic indicators under study in the same direction as in the initial period, but that they were quantitatively more pronounced. In occasional cases, however, we observed a decrease rather than an increase in arterial pressure and heart stroke and minute volumes (Figs. 1, 2, 3, and 4). It should be noted that statistically reliable changes in the hemodynamic indicators studied were not obtained in any of the series on the 15th, 53rd, and 67th days of hypodynamia. The reaction of the circulatory system to the medication differed somewhat in the series IV and V subjects, who received systematic physical and occlusion conditioning, from the hemodynamic shifts observed in the series II subjects. For most of them, the action of the medication was characterized by the same directions of the hemodynamic changes as during the initial period. Thus, for example, the average dynamic pressures of three out of four subjects also increased on the 67th day of hypodynamia, as it had in the initial period (Fig. 5).

The arterial-pressure reaction during recovery was the same as in the initial period. The action of the drugs was also accompanied by a rise in the average dynamic and maximum pressures. There were no regular changes in heart stroke and minute volumes.

Thus, the effect of the medication on hemodynamics differed in men subject to prolonged strict confinement to bed from the response to the medication that was observed in the initial period. There was an increase in some cases, a decrease in others, and sometimes even inversion of the effects. Similar results were obtained by a number of authors in experiments in which the organism was subjected to g-forces (Parin et al., 1965; Belay et al., 1967), a modified gaseous environment (Dmitriyeva, 1960; Belay et al., 1964), ionizing radiation (Vasil'yev, Saksonov, 1958), and a number of other factors.

It must be assumed that the causes of these changes during hypodynamia were deconditioning of the circulatory system and disturbance of the mechanism that regulates it.

Systematic physical conditioning during hypodynamia had a helpful influence on the state of cardiovascular reactivity; it lowered the degree of the changes and to some extent prevented inverted reactions to the medication.

Recovery of the cardiovascular responses to the set of medications used was still incomplete on the 16th day after the subjects had been returned to their normal life pattern and vigorous physical activity.

These results indicate that the use of the medications under /211
the conditions of spaceflight in the generally accepted doses may produce undesirable effects.

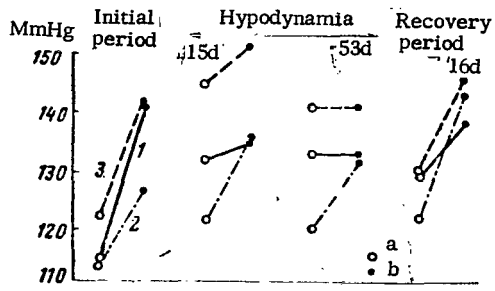

Figure 1. Variations of Maximum Pressure in Response to Medication in Subjects B-y (1), B-k (2), and G-y (3). a) Arterial pressure before medication; b) same, 1 hour after medication.

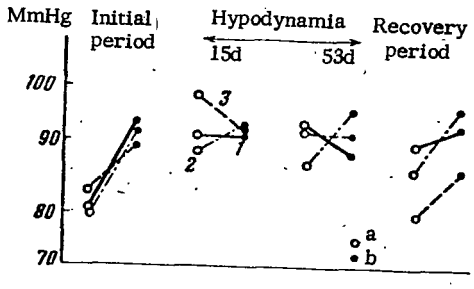

Figure 2. Variations of Average Pressure. Symbols same as in Fig. 1.

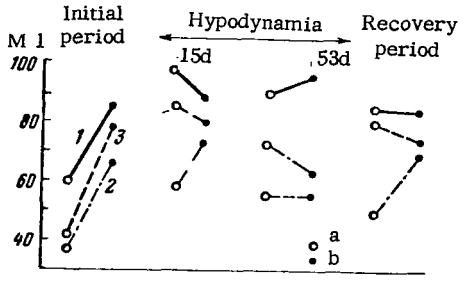

Figure 3. Variations of Heart Stroke Volume in Subjects B-y (1), B-k (2), and G-y (3). a) Heart stroke volume before medication; b) same, 1 hour after medication.

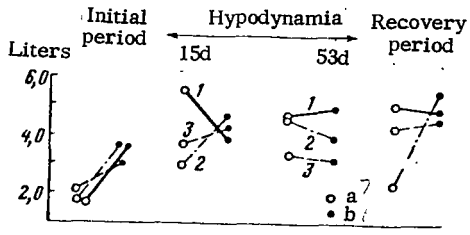

Figure 4. Variations of Heart Minute Volume. Symbols same as in Fig. 3.

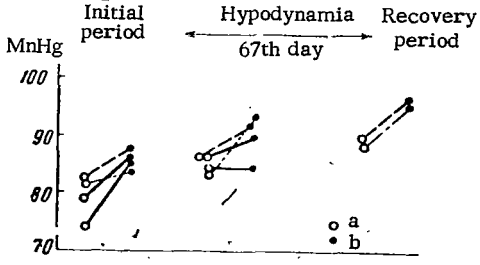

Figure 5. Variations of Average Pressure in Series IV and V Subjects. a) Arterial pressure before medication; b) same, 1 hour after medication.

There is therefore a need for special studies aimed at determining the optimum doses for medications prescribed for inclusion in spacecraft drug cabinets.

As we noted above, one of the undesirable aftereffects of hypodynamia is increased orthostatic instability.

The positive hemodynamic shifts obtained under the influence of the medication in the initial period served as a basis for use of the preparation before the orthostatic test as a collapse preventive. For this purpose, the series II, IV, and V subjects were given the medication one hour before the orthostatic test in the 9th week of hypodynamia. The results were compared with the observational data for the control group of subjects, who were strictly confined to bed without the use of any prophylactic measures.

TABLE 2. CHANGES IN CERTAIN HEMODYNAMIC INDICATORS AT THE 10th MINUTE OF THE ORTHOSTATIC TEST (in %) (9th week of hypodynamia) /212

Indicator	Experimental Series*		
	I	II	IV, V
Number of observations	3	3	3
Pulse	+56	+49	+55.5
Average dynamic pressure	+17.8	+16.1	+12.8
Heart stroke volume	-55	-52	-53
Heart minute volume	-29.2	-29.9	-17.9
Collapse	3	None	None

*The table gives averaged data for each series; - indicates a decrease and + an increase.

The joint studies of M.I. Tishchenko, V.V. Simonenko, and B.A. Korolev indicated that orthostatic instability increased in all groups during hypodynamia, but that it was most pronounced in the control. Thus, collapse was observed in all control-group subjects in the orthostatic test administered at the end of hypodynamia. In group II, whose subjects received the medication in 4 day cycles, two subjects out of three reported headaches, pain behind the sternum, dizziness, and weakness during the orthostatic test, but did not enter a collaptoid state. The series IV and V subjects, who received physical and occlusion conditioning on a daily basis during hypodynamia, showed superior tolerance of orthostatic tests. As for the hemodynamic changes in the orthostatic tests, they took the same direction in all subjects and were characterized by substantial quickening of the pulse, a rise in average dynamic pressure, and decreases in heart stroke and minute volume (Table 2). On examination of the hemodynamic shifts, our attention is drawn to the fact that the series II subjects, who had received the medications an hour before the orthostatic test, showed a somewhat lower pulse frequency than the control. There was a much smaller decrease in heart minute volume in series IV and V by comparison with the hemodynamic data of series I and II. It should also be noted that collapse developed as early as the 10th minute of the orthostatic test in all subjects of the control group, while none of the subjects observed in series II, IV, or V was observed to develop a collaptoid state.

The data given above indicate that the combination of drugs used reduces the orthostatic disturbances to hemodynamics to a certain degree, especially among the subjects who received physical conditioning during hypodynamia.

The observed effects of hypodynamia on tolerance to g-forces have been described by a number of authors (Kotovskaya et al., 1963; Miller and Leverett, 1965, and others).

The use of the combination of drugs in this study made it possible to preserve stability at the initial levels or even improve on them slightly when physical exercises and the drugs were prescribed in combination (see Kotovskaya et al., this collection). /213 However, these results were obtained with considerably greater stressing of the organism's functional systems than in the control studies.

CONCLUSIONS

1. In the initial period, the action of the mixed medication, which consisted of amphetamine, securinine, and caffeine, was manifested in increases in the average dynamic, lateral, maximum, and pulse pressures, as well as in heart stroke volume. Minute circulation volume increased and the tone of muscular-type vessels decreased slightly in some of the subjects. No consistent changes in pulse and minimum pressure were observed.

2. During hypodynamia, quantitative and qualitative changes were observed in the reactivity of the cardiovascular system to the drugs employed. Qualitatively modified reactions were encountered less frequently in the groups that were allowed physical conditioning.

3. On the 16th day after the subjects had been returned to their normal life pattern, recovery of the cardiovascular reactions to the medication used was still not complete.

4. Use of the combined medications (amphetamine, securinine, and caffeine) was accompanied by less pronounced orthostatic disturbances and higher stability to transverse g's, especially in the subjects who did physical exercises.

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STATE OF NERVOUS-SYSTEM FUNCTIONS DURING AFTEREFFECTS OF HYPODYNAMIA

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ABSTRACT: Distinct disturbances to the functions of the nervous system and the neuropsychic sphere were detected in subjects after prolonged (70-day) hypodynamia. They were manifested chiefly in the appearance of organic microsymptomatics, asthenia, vegetative cardiac instability, and akinetic hypotrophy of the muscles of the lower leg. After load tests administered at the end of hypodynamia (spinning on the centrifuge, passive orthostatic tests), the changes in the animal nervous system had increased. There was a certain tendency to preferential weakening of the left (dominant) hemisphere of the brain (the appearance of occasional signs of dextral pyramidal and sinistral "cerebellar" insufficiency). Subjects who participated in the hypodynamia experiments without preventive measures showed more pronounced functional disturbances; the disturbances were less pronounced when hypodynamia was combined with physical exercises on a treadmill and with autogenous conditioning. After hypodynamia, the functions were restored in three phases, the basic content of which was as follows: vascular-vegetative dystonia and disturbed coordination of movements (1st phase lasting from a few hours to 1-2 days), development of traumatic myositis in the lower extremities and vegetative-vascular instability (2nd phase, 3-4 weeks), and the appearance of symptoms of vegetative-vascular instability only during the load tests (3rd phase, 2-3 months). Thus, the total duration of the aftereffect of 70-day hypodynamia ranged from 3-4 months for the various subjects.

The state of the functions during the aftereffect period was evaluated on the basis of data obtained on the last day of hypodynamia, during emergence from the hypodynamic state, and at various times after the resumption of activity. In addition to the results of general clinical neurological examination, plethysmographic indicators and data from certain other studies (vegetative-vascular reactions to load tests, etc.) were taken into account.

None of the subjects had registered any complaints concerning his state of health prior to the experiment, and objective

examination had failed to turn up any nervous-system or neuropsychic pathology. Some of the subjects showed occasional peculiarities of neurological status, but these did not reflect any illness (slight anisocoria, uniformly low abdominal reflexes, etc.). The plethysmogram indicators were within the normal reaction range and were quite stable. /215

A summary of the results obtained on examination of 15 subjects on the last day of hypodynamia brought out the following symptomatics that had not been observed before the experiments:

– anisocoria in 7 subjects (with the left pupil larger than the right pupil in 6 of them);

– smoothing of the right nasolabial fold in 1 subject;

– increase in smoothness of right nasolabial fold that had existed before the experiment in 1 subject;

– right deviation of the tip of the tongue in 1 subject;

– Marinesco-Radovici symptom in 2 subjects;

– bilateral Chvostek's sign in 1 subject;

– positive chin reflex in one subject;

– general depression of reflexes in 8 subjects;

– tremor of fingers in 3 subjects;

– moderate atrophy and hypotonia of the lower-leg muscles in 12 subjects (slight atrophy of the muscles in the distal divisions of the thigh were also noted in 6 of these subjects);

– moderate hypotonia and flabbiness of the lower-leg muscles (without marked atrophy) in 3 subjects.

Thus, neurological disturbances were prominent among the clinical aspects of prolonged hypodynamia. They were even further aggravated after the extremal disturbances applied at the end of the experiment (spinning on the centrifuge, passive orthostatic test).

Seven subjects were examined after spinning on the centrifuge. Only one of them showed no changes from the initial background (prior to the spin); the changes in the other six were quite distinct and were manifested in an increase (4 subjects) or decrease (1 subject) in the tendon reflexes, suppression of abdominal reflexes (3 subjects), the appearance of a proboscis reflex (2 subjects), the Marinesco-Radovici symptom (1 subject), Bechterew's symptom (1 subject), a weakly positive bilateral

Babinskiy's symptom (1 subject), and tremor of the eyelids, tongue, and fingers (2 subjects).

Six men were studied after application of the passive orthostatic test. The following changes were noted from the results obtained before the test:

– in two subjects, smoothing of the right nasolabial fold; in one, a slight deviation of the tip of the tongue to the right;

– in four subjects, the right tendon reflexes (especially in the arms) were found to be somewhat stronger than those on the left; two subjects showed lower abdominal reflexes, and the plantar reflexes were not in evidence on the right side in the other two;

– a distinct bilateral fan sign was noted in one subject, and /216
flexion of the toes of both feet in another in response to a mallet tap on the dorsum of the foot;

– all subjects developed a faint intention tremor in the finger-to-nose test; it was more pronounced when the test was performed with the left hand;

– all subjects showed instability in the Romberg position, with a tendency to lean to the left and backward in most of them;

– five subjects deviated slightly to the left when walking with their eyes closed, and the gait of one subject was unsteady, with minor equal deviations in both directions;

– mild horizontal nystagmus appeared in one subject, becoming stronger when he looked to the left, and one subject presented uniform (in both directions) fixation nystagmus.

The symptoms of disturbances to the animal nervous systems that appeared after the load tests were unstable and disappeared during the first few hours or days after testing (i.e., immediately after resumption of activity).

Analysis of the results of neurological examination indicated that, despite the different conditions in the different experimental series, changes in the animal nervous system occur in practically all subjects and develop in about the same direction, and that the most indicative data for tolerance comparisons between the subjects of the various series were the subjective symptomatics experienced during the experiment (on the basis of anamnestic information) and after its conclusion, and the behavioral reactions and vegetative-vascular shifts, especially in the load tests.

In arriving at a comparative evaluation of the test results on the basis of these criteria, we might note that the most distinct nervous-system functional disturbances arose in the subjects who participated in the first series of experiments. One of them (Ch-y) reported headaches, poor sleep, and loss of appetite daily starting with the 6th day of the experiment, and his functional recovery during the afterperiod was sluggish. Similar but somewhat less pronounced changes were also observed in subjects K-n and M-s.

Subject K-s, however, was subject to especially pronounced neuropsychic activity disturbances. On the 20th day of hypodynamia, he developed headaches, dizziness, and nausea, and wept for no apparent reason; he could not concentrate, refused medication, experienced a persistent desire to move about, and stated that it would be impossible for him to continue the experiment. The experiment was broken off ahead of schedule because of the development of this neurotic state. It was found that from the first day in hypodynamia until the appearance of the neurotic reactions, this subject had been studying every day for his college entrance examinations. Apparently, this additional mental load constituted ultrastrong stimulation for his nervous processes /217 which were already weakened by the effects of hypodynamia, resulting in deeper asthenization of these processes and the development of the neurosis.

This case of nervous breakdown is of great prognostic importance, since it indicates that additional neuropsychic stress may, under the conditions of such experiments, have considerable influence on a man's state of health and efficiency.

The other subjects who completed the experiment of this series (K-n, M-s, Ch-y) nearly lost consciousness in the passive orthostatic test that was given a few minutes after termination of hypodynamia. All of their plethysmograms showed a sharp decrease in pulse-wave amplitude, the strength of the vascular reaction to stimulation and an increase in its duration (primitive reactions); undulating curves appeared, and certain reflexes were inverted or disappeared. These changes indicated imbalance of the nervous processes in the vasomotor-innervation sphere with predominance of inhibition and, in general, vegetative-vascular instability.

In all cases in which hypodynamia was combined with the administration of stimulants or physical exercises, the functional changes were, on the whole, much less marked both during the experiment and during the aftereffect.

Better indices were recorded in the subjects who participated in experimental series III (K-v, V. M-k, M. M-k). No subjective disorders were brought out during or after the experiment in two of these subjects (K-v and V. M-k); they remained cheerful and

sthenic and showed no appreciable fatigue reactions under mental and emotional stress; nor did their plethysmograms show changes. Only in subject M. M-k was a slight increase in irritability noted toward the end of hypodynamia; he was also moderately asthemic during the first few days after resumption of activity. His plethsmogram also showed certain changes (periodic absence of cold-stimulus and oral-counting reflexes). It appears that these reactions on the part of M. M-k reflected his individual peculiarities. No marked atrophy of the lower-leg muscles was observed in any of the subjects of this group, in contrast to the subjects who participated in the other experimental series; these muscles showed only moderate hypotonia.

In series II, two subjects out of three (B-y and G-y) reported brief headaches only rarely during hypodynamia, and B-k developed moderate general lassitude after receiving the stimulants. However, for the first 8-10 days after resumption of activity, all of the subjects tired more easily under mental exertion and suffered transient headaches and heavy-headedness; marked /218
variations of mood, ranging from moderate euphoria to slight depression, were observed in B-y. All plethysmograms showed instability of vascular tonus, a decrease in the strength of the vascular reflexes, and their inversion under the action of second-signal stimuli (oral counting).

Four subjects out of the six who participated in the series IV and V experiments showed increased irritability from time to time during hypodynamia (A-v, B-v, A-n, L-i), while three (A-v, K-ya, A-n) reported headaches, which persisted to the end of the experiment. All subjects of these groups were slightly asthenic and comparatively easily fatigued. One of them (F-v) fared poorly in the passive orthostatic test (distinct signs of impending loss of consciousness). A decrease in the vascular reactions to stimulation was determined on the plethysmograms of almost all subjects, and the reactions were altogether absent at times. These data indicate that the nervous-system functional disturbances were also stronger in the series IV and V subjects than in series III, but weaker than in series I.

Evaluation of the results of the neurological studies made at various times after the resumption of activity indicated that recovery of the functions takes place in three phases during the aftereffect period of hypodynamia.

The development of vascular-vegetative dystonia (in a number of cases, near-fainting), the appearance of a new organic microsymptomatics (in addition to that which arose during hypodynamia), and movement-coordination disturbances are characteristic for the first phase, which begins when the subjects are turned from the horizontal to the vertical position (passive orthostatic test). These changes are unstable and disappear in the first few hours or days.

The second phase of the aftereffect period lasts for 3-4 weeks. It is characterized by the development of traumatic myositis in the muscles of the lower extremities, phenomena indicating a certain asthenia and vegetative-vascular instability, and gradual recession of the organic microsymptomatics that had arisen during the experiment.

Toward the end of this phase, i.e., a month after emergence from hypodynamia, the symptoms of disturbance to the animal nervous system had almost vanished in all subjects; only in F-v did the weakly positive fan sign persist. The asthenic effects had also subsided after 1, 2, or 3 weeks in almost all of the subjects. However, the signs of vegetative-vascular instability (tremor of the eyelids and fingers, hyperhidrosis, persistent dermographism, changes in vasomotor reflexes, etc.) remained distinct throughout this phase. They were encountered more frequently and were more pronounced in the series I subjects.

From the first few days after resumption of activity, every one of the subjects complained of pains in his feet and in the muscles of his lower legs and thighs, which caused particular discomfort in walking. Palpation of the muscles was distinctly painful. The pains in the muscles had vanished after 3-4 weeks, with full recovery of their trophics and tone. /219

In the third phase, the functions recovered completely. This took from 2 to 3 months after completion of the 2nd phase, depending on the subject, i.e., the total duration of the aftereffect of 70-day hypodynamia was 3-4 months. The slowest recovery of the functions was observed in the series I subjects.

This phase was characterized chiefly by instability of the vegetative-vascular indicators in the load tests (spinning on the centrifuge, physical-exertion test, etc.), while the vegetative disturbances noted previously in the state of rest gradually abated. Three to four months after resumption of activity, the disturbances to nervous-system functions (including those that appeared during load tests) had been fully corrected in all subjects.

Thus, the disturbances to the nervous system and the neuropsychic sphere during prolonged hypodynamia are quite distinct. They are manifested chiefly in the appearance of an organic microsymptomatics, asthenia, vegetative-vascular instability, and akinetic hypotrophy of the lower-leg muscles. After load tests (spinning on the centrifuge, passive orthostatic tests), the changes in the animal nervous system show a brief but substantial increase. Here we note a certain tendency to preferential weakening of the left (dominant) hemisphere, as manifested in the appearance of the individual signs of dextral pyramidal insufficiency (smoothing of the nasolabial fold, enhancement of tendon reflexes, suppression of skin reflexes, etc.). We cannot exclude the

possibility that the sinistral "cerebellar" symptomatics that appears after the orthostatic test (instability in the Romberg position with a tendency to fall backward and to the left, slight deviation to the left in walking with the eyes closed, etc.) also reflects weakness of the left brain cortex, and of its frontal lobe in particular.

The most probable cause of the organic microsymptomatics that appears during hypodynamia consists in disturbances to the blood circulation of the brain. This hypothesis is supported by the fact that the microsymptomatics increases especially distinctly after the orthostatic test, which was the first step in the transition from prolonged hypodynamia in the supine position to the vertical position, at a time when vascular tone is down and the blood displaces into the lower half of the body by virtue of the laws of hydrostatics.

The development of unilateral pyramidal symptomatics under /220
these conditions can be explained in some cases by the revelation of latent defects of the central nervous system as a result of circulatory hypoxia. Thus, a year before this experiment, subject G-y had suffered a slight brain concussion, which was followed by determination of enhanced tendon reflexes and depression of abdominal reflexes on the right side. These symptoms subsided with time. No anisoreflexia was detected before the hypodynamia experiment or on inspection on the last day of hypodynamia, but the signs of slight dextral pyramidal insufficiency reappeared after the passive orthostatic test, to disappear within a day.

In all other cases, however, there were no indications of past cranioencephalic trauma or neural infections. It may therefore be assumed that reduced blood filling of the brain is the primary and major factor in disturbing the functions of the dominant hemisphere, as expressed in right-handed persons in the appearance of microsymptoms of dextral pyramidal insufficiency. Further research will be necessary to refine the hypothesis advanced above.

CONCLUSIONS

1. The disturbances of nervous-system function during the afterperiod of hypodynamia were most pronounced in the subjects of series I (where no preventive measures were taken), and least pronounced in series III (physical exercises on the treadmill and autogenous conditioning).

2. The aftereffect period of prolonged hypodynamia has three phases. The total duration of this period after the 70-day experiment was found to be 3-4 months, i.e., 1.5 to 2 times as long as the hypodynamia itself.

3. It is difficult to explain the organic neurosymptomatics that appeared during hypodynamia and in the load tests during the period of emergence. This calls for a search for a number of auxiliary methods (rheoencephalography, polydynamometry, etc.) and their introduction into research practice.

RESULTS OF INVESTIGATIONS OF THE CARDIOVASCULAR SYSTEM DURING THE AFTEREFFECT OF 70-DAY HYPODYNAMIA

/221

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N.V. Pisarenko, and Ye.Ye. Sheludyakov

ABSTRACT: This article sets forth data on the aftereffect of prolonged hypokinesia and evaluates the effectiveness of the preventive measures taken against its unfavorable effects on the basis of the stability and degree of the changes in the circulatory system. During 1-3 days before the start of the experiment and in the afterperiod until the changes noted had vanished, the subjects were examined by a therapist who used generally accepted clinical methods; electrocardiograms were recorded, hemodynamics was studied by N.N. Savitskiy's method at rest, after measured physical exertion, and during the passive orthostatic test. The results of five series of experiments in which 15 subjects participated were studied. Electrocardiographic examination during the afterperiod showed a change in the bioelectrical activity of the heart and disturbance of metabolic processes in the myocardium. The hemodynamic changes indicated disturbance of cardiovascular regulation and poor adaptation of the system to physical exertion and orthostatic disturbances. These shifts were most distinct and protracted in the series I subjects ("pure hypokinesia"). The smallest changes were found in the individuals of series III, where hypokinesia was combined with physical exercises on a treadmill.

The basic objectives of the present study were investigation of the aftereffect of hypodynamia (series I) and evaluation of the effectiveness of preventive measures (series II-V) on the basis of the persistence and magnitude of the circulatory-system changes during the afterperiod.

Therapeutic status was studied. Electrocardiograms were taken at rest in 12 leads and after physical exertion (15 squat jumps) in the 3 standard leads. Hemodynamics was studied by N.N. Savitskiy's method at rest and during the load tests. The functional tests used were measured physical exertion (pullups to a height of 0.5 m for 5 minutes at a rate of 30 pullups per minute) and a passive orthostatic test (rotation thorugh 85° from the

horizontal plane for 5 minutes).

The subjects were examined over the 1-3 days prior to the experiment in the control phase. During the aftereffect, they were kept under observation until the detected shifts had disappeared. K-n and Ch-y (series I) were observed beginning at the 15th-23rd days after the end of hypokinesia. The other subjects were observed for the first 3-6 days and on the 15th day of the aftereffect period. Fifteen subjects were studied in five series (see Sorokin et al., this collection).

EXPERIMENTAL RESULTS

First series. The general condition of the subjects was satisfactory. All complained of general fatigue and heartburn. Objectively, the skin and visible mucous membranes were pale.

No pathological changes in the internal organs were found. The changes detected in the EKG indicated lowered bioelectric activity of the heart and disturbance of metabolic processes. This was indicated by decreases of 10-12% in the voltage of the R deflection and 17-50% for the T deflection, and an increase in the systolic index by 5-10% over the ideal values. Under measured physical exertion, the systolic index exceeded the ideal by 6-16%, indicating indirectly disturbance to the contractile capacity of the cardiac muscle. In the background study, the systolic index did not deviate by more than 1-5% from the ideal. These peculiarities of the electrocardiograms persisted for 2 months.

The hemodynamic changes showed phasing (Fig. 1). Immediately /222 after release from restricted mobility, circulation minute volume increased by 8-22%. Pulse rate rose to 12-25% above the initial value. Disturbance to cardiovascular regulation was manifested in lack of conformity between the variations of blood minute volume and those of peripheral resistance and in a decrease in vascular tone. On the 18th day of the aftereffect period, circulation minute volume had increased even further, but because of an increase in heart stroke volume, the average dynamic pressure had approached its initial value and vascular tone had normalized. On the 125th day of the afterperiod, a distinct tendency toward normalization of the basic hemodynamic indicators was observed.

Under measured physical exertion, blood minute volume increased basically as a result of pronounced tachycardia. Stroke volume decreased during the first minute after exertion, to recover after 3-5 minutes of relaxation. The hemodynamic indicators took more than 5 minutes to recover. These features of the hemodynamic changes in the physical-exertion test were observed for 15 days. They indicated lowered tolerance of physical stress. By way of example, we present the results of a physical-exertion test for subject K-n (Fig. 2).

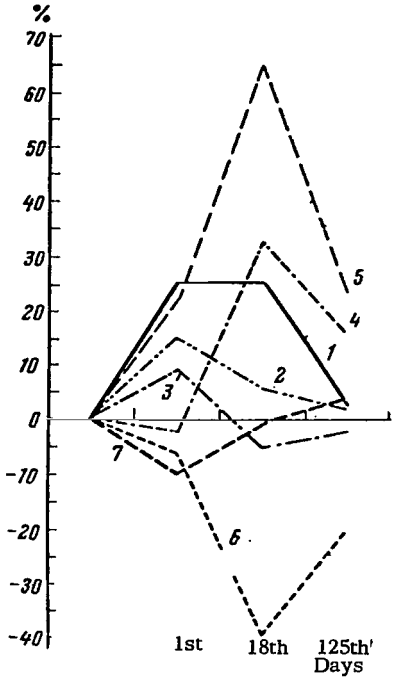

Figure 1. Variation (in % of original) of Basic Hemodynamic Indicators at Rest in Subject K-n (series I) Over the Days of the Aftereffect Period. 1) Heart rate; 2) average dynamic pressure; 3) lateral systolic pressure; 4) heart stroke volume; 5) blood minute volume; 6) peripheral resistance; 7) elastic-modulus ratio Vm/Ve; 8) contractile power of left ventricle.

Under the influence of the experimentsl conditions, subjects K-n and M-s showed a substantial decrease in their tolerance for the orthostatic test, which was given on the 3rd day during the aftereffect period (Fig. 3). After they had been standing for 1-3 minutes, pulse pressure dropped with

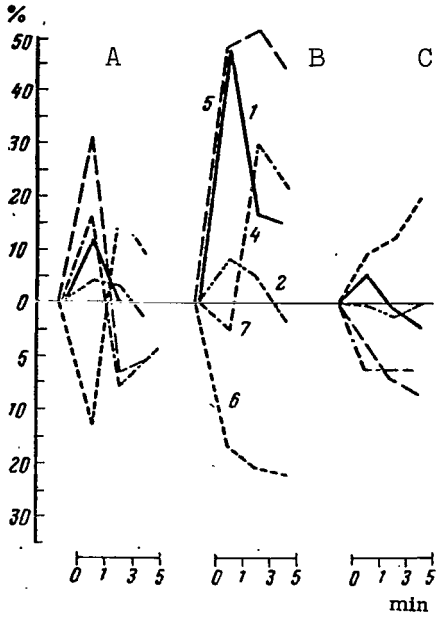

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Figure 2. Reaction of Cardiovascular System to Physical Exertion in Subject K-n (Series I). A) Before hypokinesia; B) on 3rd day of aftereffect period; C) on 15th day of aftereffect period. Symbols same as in Fig. 1.

/224

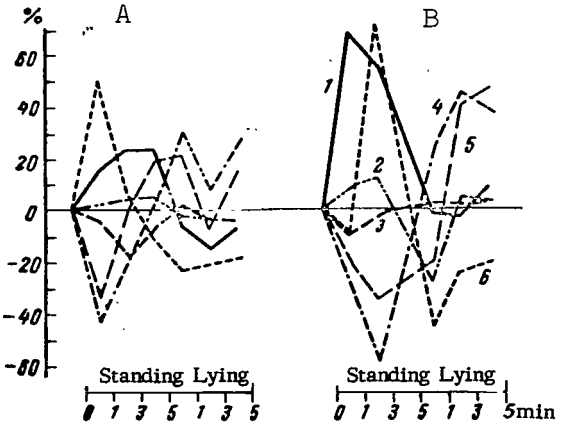

Figure 3. Reaction of Cardiovascular System to Passive Orthostatic Test in Subject M-s (Series I). A) Before hypokinesia; B) on 3rd day of aftereffect period. Symbols same as in Fig. 1.

an increase in diastolic pressure. Despite quickening of the pulse, circulation minute volume decreased owing to a substantial decrease in heart stroke volume. The decrease in the ratio of the pulse-wave propagation velocities along muscular (Vm) and elastic (Ve) vessels was larger than in the initial state, indicating lower tone of the major arteries. This loss of tone was accompanied by a marked increase in peripheral resistance. The hemodynamic indicators had not reached heir initial level by the 5th minutes of the recovery period. An orthostatic test given again after 15-17 days showed no tolerance differences from the background.

Second series. The nature of the complaints and the general state of the subjects were the same as in series I after the experiments conducted in this series.

Change in cardiac-muscle bioelectric activity was manifested in higher P and T deflections (by 10-25%) on the EKG and by elevation (by 7-15%) of the systolic index over the ideal values, chiefly after measured muscular exertion.

No pronounced shifts were found in the functional state of the cardiovascular system for Ch-y and B-k when these subjects were at rest. Subject B-y showed a decrease in the Vm/Ve ratio (by 23%) and in heart minute volume (by 7%) and an increase in all other arterial-pressure indicators (by 15-20%). The change in the duration of the cardiac systole phases conformed to the changes in the hemodynamic situation. /224

There was no change in tolerance to the physical exertion test in Ch-y and B-y. B-k did not tolerate it as well. In his case, a slackening of the pulse and lower pulse pressure, blood stroke and minute volumes, left-ventricle power, and the Vm/Ve ratio were observed at the 3rd minute after exertion.

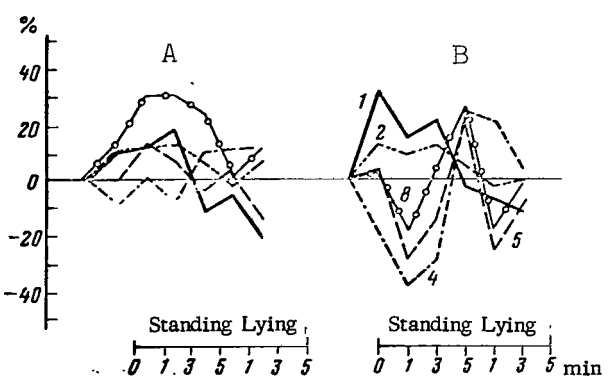

Figure 4. Reaction of Cardiovascular System to Passive Orthostatic Test in Subject B-n [sic] (Series II). Symbols Same as in Fig. 1.

Two subjects (B-k and B-y) showed lowered tolerance to the orthostatic test. The decreases in pulse pressure, stroke volume, and left-ventricle power were greater for these subjects in the vertical position than they had been initially. An example of the hemodynamic reaction to the orthostatic test after series II appears in Fig. 4.

Third series. Only one subject complained of

rapid fatiguing when he walked. Electrocardiographic study revealed shifts indicating a certain increase in the bioelectric activity of the cardiac muscle (the voltages of the R and T deflections increased by 10-20 and 20-50%, respectively). The systolic index exceeded the ideal value by 10-15%. /225

The hemodynamic changes under resting conditions and during physical exertion were moderate. The direction that they took was determined by the individual peculiarities of the subjects. The change in the phase durations of the cardiac systole corresponded to the changes in intracardiac hemodynamics. On the 17th-18th days of the aftereffect period, the physical-exertion test was tolerated as well as it had been initially. The response to the orthostatic test administered during the control period consisted in a slightly greater quickening of the pulse (by 10-27 as against 3-14%) and a more pronounced drop in Vm/Ve (by 11-27 as against 4-15%), with a simultaneous increase in peripheral resistance.

Fourth series. The general condition of all subjects was satisfactory. The subjects stopped complaining of general weakness after a month or a month and a half.

Repeated registration of electrocardiograms for comparison with the initial records showed a decrease in the voltages of the R and T deflections, by 10-40 and 15-30%, respectively. No substantial increase in the systolic index was noted, either at rest or during physical exertion. The lower EKG voltage persisted for two months.

Pulse frequency at rest was 50-80% above the initial value. The arterial-pressure indicators showed a moderate increase. Circulation minute volume had risen 31-53% with an adequate drop in peripheral resistance.

The response of the circulatory system to physical exertion was stronger than during the control period. The increases in /226
pulse frequency, blood minute volume, and left-ventricle power exceeded their initial values. Thus, the pulse had quickened by 5-9 beats per minute and blood minute volume had increased by 50-90% in response to physical load before hypodynamia. The average dynamic pressure had risen by 5-10 mmHg. After 17-18 days under the conditions of the experiment, these indicators increased by 6-16 beats/min and 60-105%, respectively, in response to physical exertion. After 45-49 days, the results from this test showed practically no differences from the initial results.

The hemodynamic peculiarities of this series were determined by the conditions of hypokinesia; moreover, the functional state of the cardiovascular system was influenced by an affliction with acute otitis (subject K-ya) and an appendectomy by reason of acute appendicitis (subject A-v) during the experiment.

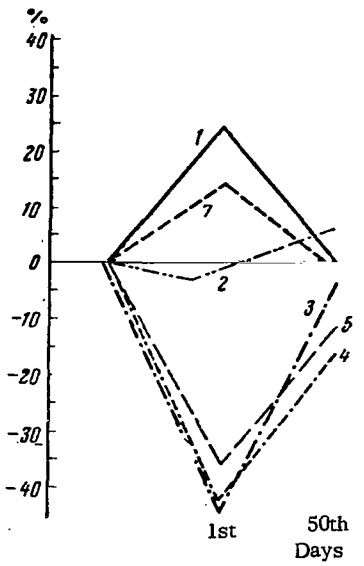

Figure 5. Variation of Basic Hemodynamic Indicators at Rest in Subject L-i (Series V) Over the days of the Aftereffect Period. Symbols Same as in Fig. 1.

Fifth series. The subjects complained of general weakness and fatigue, which disappeared after 7-12 days.

The differences between the electrocardiographic indices registered on the 1st day after resumption of normal motor activity and the initial values were insignificant. They included a slight increase in the voltages of the P and T deflections, which recovered their initial amplitude after 5-7 days. On the 1st day, a single ventricular extrasystole was registered for subject L-i. No subsequent extrasystolic arrhythmia was detected.

Examination of the subjects at rest /227 showed quickening of the pulse and an increase in arterial and especially the average pressure. Pulse pressure and stroke volume were down (24-34%). The largest hemodynamic changes in the state of rest occurred in subject L-i (Fig. 5). He was found to have distinctly lowered pulse pressure (by 16 mmHg), systolic blood volume (by 47%), and left-ventricle power (by 43%) owing to a decrease in the volumetric rate of ejection. These changes indicated deterioration of myocardial contractility when A-n and L-i were examined 49 days later.

A physical-exertion test evoked a substantial increase in the reaction of the circulatory system and slow recovery of the system. After 49 days, the response of the cardiovascular system to physical exertion showed no differences from the background.

The results of the clinical-physiology studies made during the aftereffect period of 70-day hypokinesia confirm conclusions drawn previously to the effect that many days of hypokinesia influence the cardiovascular system and the circulatory regulation mechanisms (Myasnikov, Akhrem-Akhremovich, Kakurin et al., 1963; Vanyushina, 1963, Buyanov, Beregovkin, Pisarenko, 1967; Mikhaylovskiy, Benevolenskaya et al., 1967, and others).

The hemodynamic changes that took place as a result of restricted mobility in a nearly horizontal position were manifest under the conditions of rest and especially when the load tests were administered.

Comparison of the series I ("pure hypodynamia") data with those of the other series showed smaller detrimental shifts in the series in which the preventive measures had been taken. The deviation of the hemodynamic indicators at rest and in the functional tests from their background values were less pronounced and recovered more rapidly in series II-V. The best results were obtained in series III, where hypodynamia was combined with physical exercising on a treadmill.

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REGIONAL ARTERIAL OSCILLOGRAPHIC INDICES DURING HYPODYNAMIA

Ye.G. Ryabkova and I.I. Shantyr'

ABSTRACT: Oscillograms from symmetrical zones of the upper arms and lower legs, the Korotkov arterial pressure, and pulse frequency were registered systematically over the course of the experiments. Prolonged hypodynamia resulted in neurocirculatory dystonia, which manifested in asynchronous variations of arterial pressure and vascular tone and asymmetry and instability of the vascular reactions.

Functional disturbances of the cardiovascular system are among the basic manifestations that arise in prolonged hypokinesia.

We studied the state of the cardiovascular system by the oscillographic method. The oscillograms were recorded with an arterial oscillograph from symmetrical areas of the upper arms and lower legs. Pulse frequency and arterial pressure (by the Korotkov method) were registered simultaneously. The examinations were made on the eve of the experiment and thereafter every 7-10 days during the experiment, at the same hour of the day.

Marked changes in arterial pressure and vascular tone were observed during the long confinement of the subjects to the horizontal position with maximum restriction of mobility.

During the first twenty days, the maximum pressure in the vessels of the arms was unstable, but showed a persistent downward tendency. From the 40th through the 50th day, it rose again approximately to the original values, and then declined again. The maximum pressure in the vessels of the lower legs dropped more sharply, and had stabilized at a low level 30 days from the start of the observations.

The minimum pressure in the vessels of the arms and legs did not vary as widely: it decreased in the brachial arteries and rose gradually in the vessels of the lower leg.

The average pressure varied in parallel with the maximum and minimum pressures in the vessels of the arms, but only with the minimum pressure in the leg vessels.

During the enforced prolonged rest, the oscillograms flattened out sharply, some of them taking the form of straight lines — an effect that most authors treat as indicating an increase in vascular tone. This was particularly sharply in evidence for the vessels of the lower extremities and was possibly of a compensatory nature. Measurements of arterial pressure by auscultation often resulted in figures higher than those obtained by arterial oscillography. This can serve as an additional criterion of the upward change in vascular tone.

It must be noted, however, that the changes in the oscillatory index during hypodynamia may be functions not only of the state of vascular tone, but also, and primarily, of the systolic ejection and conduction through the precapillary bed. The observations of authors who investigated vascular tonus in the brachial /229
arteries by other methods have indicated that hypodynamia lowers it.

Our studies indicated the absence of parallelism between the state of vascular tone and arterial pressure in the various regional basins, something that had not been observed prior to hypodynamia.

The vasomotor-reaction changes that were brought out during hypodynamia may indicate failure of compensation and automatic regulation, which usually occur in the healthy organism and are disturbed by various pathological states and in individuals who are out of physical "shape."

Pulse quickened during the experiments, indicating a relative increase in the tone of the sympathetic nervous system.

We observed the same subjects during their emergence from the state of hypodynamia.

The orthostatic test given immediately after hypodynamia indicated an even greater decrease in the oscillations of not only the leg vessels, but also those of the arms, in combination with tachycardia and other unpleasant sensations.

Oscillograms recorded from two subjects a day after the centrifuge experiments showed a sharp increase in the oscillographic index with the appearance of negative waves that were almost equal in magnitude to the systolic oscillations. No physiological reflex increase in vascular tonus in the extremities was noted in these subjects during the orthostatic test following centrifuging. In spite of the moderate decrease in the maximum and minimum pressures, these subjects withstood the orthostatic test with greater difficulty.

The oscillographic indices for the group of subjects who had received the combination of tonic drugs for the nervous and

vascular systems during hypodynamia were as follows: the maximum pressure in the arm vessels remained within the physiologically normal limits throughout the experiment, although it was somewhat high during the first month. The systolic pressure in the vessels of the lower legs decreased, and was 20-25 mmHg below the initial level by the end of hypodynamia. The minimum pressure in the leg vessels gradually increased.

All subjects of this group registered an undulating variation of the oscillographic index, but this quantity did not rise above the initial level in a single measurement for the vessels of the lower extremities, and it remained persistently low after 37 days of the experiment.

A distinct drop in the arterial-pressure and vascular-tone indicators with a tone increase in the vessels of the lower extremities was registered for several days after centrifuging for transverse g's.

The oscillographic indicators had not yet reached their initial values 14 days after termination of the experiment.

The oscillographic indicators were highly labile, but remained within the limits of the physiological norm, in the group of subjects who had been allowed measured physical exercise during hypodynamia. /230

Arterial pressure was unstable and there were still signs of vascular hypotonia on the 10th day after subjection to g-forces.

The subjects emerged in considerably better condition from hypodynamia with measured physical exertion and occlusion conditioning. This was also objectivized in the oscillographic indicators.

Orthostatic and clinostatic tests on the 61st day of hypodynamia indicated functional disturbances of the cardiovascular system. A more strongly inverted reaction was registered on the oscillograms for the lower extremities. In the orthostatic tests, the oscillograms presented the form of straight lines, and in the clinostatic test the parasympathetic reaction of the vessels was weak and substantially different from the background results. The same tests given on the 10th day after the end of the experiment indicated a more physiological reaction of the cardiovascular system to passive load, but the results still differed from the normal initial indicators.

To summarize the observations, we may conclude that prolonged hypodynamia results in a clear neurocirculatory dystonia, which is manifested in asynchronous variations of arterial pressure and vascular tone and asymmetry and instability of the vascular

reactions. This dystonia was traced most distinctly in the experiment conducted with no prophylactic measures.

AN INVESTIGATION OF ORTHOSTATIC STABILITY AFTER PROLONGED HYPODYNAMIA

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B.F. Asyamolov, V.V. Simonenko, and A.Ye. Baykov

ABSTRACT: The reactions of the cardiovascular system to the orthostatic test are examined in men who were restricted to the horizontal position for 70 days. Certain prophylactic measures taken against detrimental effects of prolonged hypodynamia are evaluated. The possible mechanisms of the orthostatic disturbances that result from simulation of weightlessness are discussed.

The problem of returning the cosmonauts safely to the earth occupies an important place among the problems whose solution will to a substantial degree determine future prospects for man's conquest of outer space. At the same time, the experience accumulated thus far indicates that even a short time spent in weightlessness lowers the stability of the organism to the factors that /231 are specific for life on the earth. During his evolutionary development, man has acquired a vertical orientation with respect to the earth's surface, and has, at the same time, adapted to the action of gravity in the direction of his body's longitudinal axis. The state of weightlessness and conditions that simulate this state result, as we now know quite well, in the development of a whole series of shifts, of which lowered stability to the vertical position is one important example.

According to a number of authors (Gazenko, Gyurdzhian, 1965; Buyanov et al., 1966; Taylor, David et al., 1966; Berry et al., 1967), the orthostatic-test reactions of cosmonauts after spaceflights have been characterized by more pronounced changes on the part of the cardiovascular system as compared with the preflight period, and in some cases by orthostatic collapse. Current thinking is that shifts in water-salt metabolism and muscular and vascular tone, which are, in turn, determined by the absence of blood hydrostatic pressure and lowered motor activity under the conditions of weightlessness, lie behind this phenomenon (Kakurin, Biryukov, 1966; Buyanov, et al., 1966; Graveline, 1962; Gauer et al., 1965; Dietrick et al., 1948; Lamb et al., 1965). The orthostatic test permits relatively fine evaluation of the state of regulation of the organism's most important functions and systems

to the specific action of gravity in the direction of the body's longitudinal axis, and makes it possible to bring out potential insufficiency of such regulatory mechanisms. It has come into widespread use, for example, in studies in which the effects of weightlessness on the organism were simulated by confinement to bed or by immersion of the subjects in an appropriate medium (Buyanov et al., 1966; Lampusov, 1966; Miller et al., 1965; Vogt, 1967). It has been found that the deadaptation of the organism to gravity that results from restriction to the horizontal position, along with the effects obtained by the use of various preventive measures, is reflected to a considerable degree in the nature of orthostatic stability.

Naturally, determination of reactions to the orthostatic test was extremely important in the present study, whose basic objectives were to establish the shifts that arise under prolonged (70-day) simulation of weightlessness and to test a number /232
of principles for prophylaxis of these shifts.

METHOD

The state of orthostatic stability was evaluated in sixteen subjects at three basic stages of the 70-day hypodynamia experiment: during the background study, during hypodynamia and at its /232
termination, and during the recovery period. Since the series

TABLE 1. CONDITIONS OF ORTHOSTATIC TESTS

Period	Test	Conditions	Notes on Conditions
Background study	OS-1	70°, 15 min	—
	OS-2	90°, 10 min	24 hours after centrifuge spin
End of hypodynamia	OS-3	70°, 15 min	9th week of experiment
	OS-4	90°, 10 min	End of 10th week, 24 hours after centrifuge spin, before emergence from hypodynamia
Recovery period	OS-5	70°, 15 min	2nd week of recovery period
	OS-6	90°, 10 min	4th week of recovery period

of experiments are described in detail in another article, we note only that the orthostatic studies were made in all five series. It was felt necessary to duplicate the orthostatic tests at the basic stages of the experiment in order to acquire more reliable results. Two modifications of the technique were used here. In one case, the table was inclined to 90° from the horizontal in a 20-minute test; the other lasted 15 minutes at 70°. In both cases, tensioning of the musculature of the lower extremities was excluded on transfer to the vertical position by equipping the

orthostatic table with a seat (Table 1).

Use of the two methods to rate orthostatic stability made it possible to follow the peculiarities of the reactions to these two disturbances, compare them with one another, and determine the directions taken by the shifts in orthostatic stability that arise under the influence of hypodynamia.

During the tests, the following indicators were registered at 1-minute intervals:

- the electrocardiogram in the standard and precordial leads;
- the seismocardiogram or phonocardiogram;
- sphygmograms of the carotid, femoral, and radial arteries;
- the tachyoscillogram of the brachial artery.

The hemodynamic indicators and the phase structure of the cardiac cycle were determined on the basis of the collected material, and an electrocardiographic analysis of cardiac activity was prepared. Also investigated in the orthostatic tests were certain external-respiration indicators (pulmonary ventilation, gas exchange); these are described in a separate report.

The qualitative shifts, whose most characteristic features /233
are the development of function decompensation manifested in the appearance of bradycardia, lowered pulse pressure and systolic volume, and a state of near collapse or collapse, were examined as the most distinct form taken by the orthostatic shifts. Shifts of these types served to indicate whether the orthostatic test should be broken off ahead of schedule and, in essence, no additional quantitative criteria were required to establish the fact of lowered orthostatic stability.

On the other hand, in those cases in which no signs of function decompensation developed over the scheduled time of the orthostatic test, the degree of the orthostatic shifts was evaluated on the basis of quantitative indicators characterizing changes in cardiovascular activity. Here the data obtained in the minute-by-minute registrations of physiological functions, both in the period preceding orthostasis and during the orthostatic test itself, were averaged and compared. This method of reducing the data helped bring out the most stable trends in the functional changes of the cardiovascular system.

RESULTS

The initial condition of the subjects before the orthostatic tests was different at different stages in the experiment. Toward the end of hypodynamia, a statistically reliable increase in

TABLE 2. AVERAGE INDICATORS OF PULSE FREQUENCY, PULSE PRESSURE, AND SYSTOLIC BLOOD VOLUME IN 10-MINUTE ORTHOSTATIC TESTS AT 90°

Series and conditions	Pulse frequency, beats/min			Pulse Pressure, mmHg			Systilic Volume, ml		
	OS-2	OS-4	OS-6	OS-2	OS-4	OS-6	OS-2	OS-4	OS-6
I Horizontal	72,0	81,0	68,0	42,0	39,0	41,0	90,8	64,5	96,5
Vertical	84,7	126,0	86,0	38,0	30,0	41,0	59,4	29,9	61,1
Changes, %	+18	+56	+26,5	—9	—23	—	—34	—53	—36,2
II Horizontal	67,0	88,4	60,0	32,7	37,6	33,5	66,7	56,6	67,8
Vertical	89,5	128,9	79,5	30,9	25,6	35,4	46,2	27,4	56,5
Changes,%	+33	+46	+33	—5,5	—32	+6	—30,5	—51,5	—16,5
III Horizontal	74,0	84,5	68,5	32,9	32,4	35,4	82,8	66,1	105,0
Vertical	84,5	117,3	91,2	27,0	24,8	30,1	44,6	30,1	55,0
Changes, %	+14,5	+38	+33,5	—17,5	—23	—14,5	—46	—54,5	—47,5
IV Horizontal	65,5	75,3	70,4	36,6	33,1	32,7	82,8	69,0	85,5
Vertical	84,5	122,5	85,1	35,0	27,0	29,4	52,5	34,2	44,6
Changes, %	+30	+63	+21,5	—4	—18,5	—10	—36,5	—50,5	—47,5
V Horizontal	67,0	86,5	67,2	34,6	33,5	32,6	77,0	69,0	85,5
Vertical	91,8	136,3	96,5	34,5	24,9	30,7	41,1	27,8	43,8
Changes, %	+37	+58	+43	—	—25,5	—5,5	—46,5	—59,5	—49

pulse frequency by 9-21 beats/min was noted in all series except III. In addition, mechanocardiographic data showed an increase in the minimum, average, and lateral pressure indicators to [sic] 12-17 mmHg and an 8-25-ml decrease in systolic volume. A trend to gradual normalization of these indicators was noted during the recovery period.

In the background study, the state of orthostatic stability was characterized by moderate shifts in pulse frequency (increase to 84-92 beats/min), pulse pressure (decrease to 27-38 mmHg), and systolic volume (decrease to 45-59 ml). The intrasystolic index, defined as the ratio of the duration of the blood-ejection phase to the duration of mechanical systole and expressed in percent, dropped somewhat below the ideal values, amounting to 79-82%. The myocardial tension index (ratio of the duration of the tension period to the total duration of systole (in %) increased and exceeded the ideal values to some extent at 31.8-34.8%. The average rate of ejection of blood from the left ventricle was also moderately lower (192-214 ml/sec). The velocity of pulse-wave propagation along elastic-type arteries increased, and the Vm/Ve coefficient decreased. /234 Blood minute volume decreased, but only slightly, holding at the 3.8-5.0-liter level. Peripheral resistance increased slightly. Here, electrocardiography indicated a moderate rotation of the QRS vector to the right (by 5-10°) and a clockwise rotation about the longitudinal axis. In the vertical position, the T_3 deflection was flattened. The angular distance between the QRS and T vectors varied in the normal range (up to 60°). No disturbances to the conduction function were observed in the vertical position during the initial period. Application of the orthostatic tests at the final stage of hypodynamia resulted in the development of much more pronounced orthostatic disturbances. Since, as it developed, the data obtained in the 70° orthostases reflect the same directivity of the shifts as the data of the 90° orthostatic tests, there is no need to encumber the present exposition with numerical material from all six tests. Comparison of the results from OS-2, OS-4, and OS-6 (90°, 10 minutes, before start of experiment, on 70th day of hypodynamia, and one month after its termination) will be sufficiently illustrative.

Table 2 collects the numerical data characterizing certain of the most important indicators in these tests. The relative changes in pulse frequency and systolic volume that arose in the orthostatic tests are illustrated by Fig. 1.

Analyzing the data given in Table 2 and Fig. 1, we cannot fail to observe that on the whole the degree of the orthostatic disturbances in OS-4 is considerably in excess of the shifts noted in OS-2. There is also sufficient basis for comparing the results /236 between the individual series. The following must be taken into account here. Three series I (control) subjects collapsed when given the orthostatic test on the 70th day of hypodynamia. The fourth subject of this series (K-s, who dropped out of the experiment on the 23rd day of confinement to bed, also responded to the

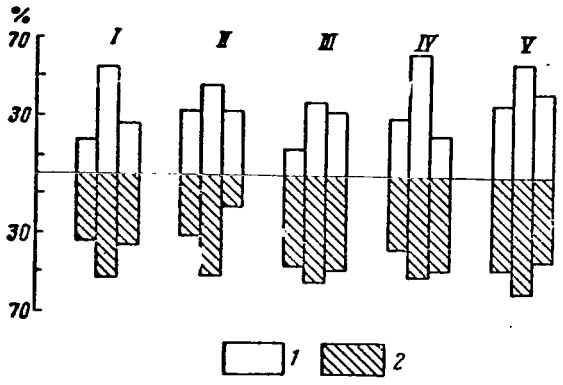

Figure 1. Relative Changes in Heart Frequency (1) and Stroke Volume (2) in OS-2, OS-4, and OS-6 for Series I-V.

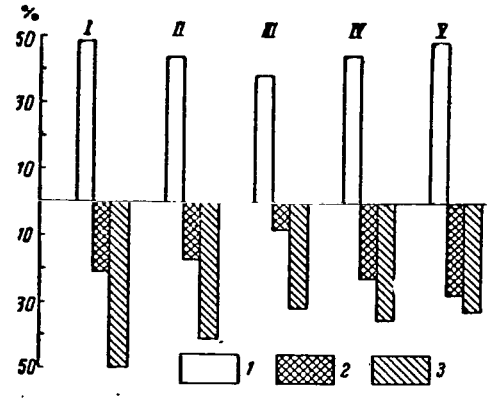

Figure 2. Relative Changes in Heart Frequency (1), Pulse Pressure (2), and Stroke Volume (3) in OS-4 by Comparison with OS-2 in Series I-V.

orthostatic test by fainting).

Thus, even without resorting to analysis of quantitative criteria, we may conclude an extremely sharp drop in orthostatic stability for this group. In series V of the experiments, one subject (F-v) also collapsed in OS-4, while the two other participants in this group, one of whom had sustained an appendectomy (L-i) 10 days before the end of the experiment, responded to orthostases with extremely wide shifts. All of this was also reflected in the group-averaged data, which give a generally unfavorable impression. The orthostatic shifts were also highly conspicuous in series II and IV, but somewhat smaller in series IV. Finally, the data on series III stand out as best against the general background, alhhough it cannot be denied that orthostatic disturbances also occurred in this case. These relationships among the individual experimental series are also preserved when the reaction to OS-2 is taken as the initial reaction for each group and the changes observed in OS-4 are compared with it after conversion to percentages. This is illustrated by Fig. 2. More pronounced changes were also noted in OS-4 on the part of the /237 intrasystolic index, which dropped to 73-78% in all series except III. The myocardial tension index rose to 38% in series III and to 40-44% in the others. The average rate of blood ejection from the left ventricle dropped to 159-217 ml/sec. Minute blood volume decreased more conspicuously than in the background study, but was nevertheless held in the 3.5-4.2-liter range by the high pulse frequency, except for the periods immediately preceding collapse. The increase in peripheral resistance was also more distinct.

In addition, the orthostatic tests at the final stage of hypodynamia showed retardation of atrioventricular conduction, conduction through the right branch of the buncle of His, and

prolongation of electrical systole by 0.04-0.06 sec above the ideal value. The vertical position produced high, sharp $P_{2,3,aVF}$ deflections, $Q_{2,3}$ deflections appeared, the amplitude of the $R_{2,3,aVF}$ deflections increased, the height of R_1 was reduced, and the S_1 deflection was deepened. The S-T segment shifted below the isoline in the 2,3, aVF, and $V_{5,6}$ leads, and above the isoline in the aVL and aVR leads. The $T_{2,3,aVF,V_6}$ deflections became negative, and the $T_{V_{1-3}}$ deflections were high, sharp, and equilateral. The $T_{V_1} > T_{V_6}$ syndrome became positive. Displacement of the QRS complex to the right was observed, along with clockwise rotation about the longitudinal axis. Vector analysis brought out a sharp rotation of the QRS vector to the right and of the T vector to the left; the vectors were shorter, and the angular distances between $\hat{QRS}$ and $\hat{T}$ and between $\hat{QRS}$ and the ventricular gradient had increased; the ratio of the gradient to the QRS vector had dropped to 40-80%.

Weakening of tone I and splitting of tones I and II, with a periodically appearing tone III were observed on the photocardiogram in the vertical position. The transformation phase did not change, but the phase of rising intraventricular pressure was longer. The tension period also increased in the vertical position by 0.02-0.03 sec, reaching 0.14-0.15 sec. The ejection period was shorter and 0.07-0.08 sec below the ideal value.

As is seen from the data given in Table 1 and Fig. 1, investigation of orthostatic reactions during the recovery period made it possible to establish an increase in orthostatic stability, but in most cases, recovery to the initial condition was still incomplete a month after termination of the experiment.

DISCUSSION

In evaluating the state of the subjects' orthostatic stability during various stages of the prolonged-bedrest experiment, we feel compelled to include at least a brief analysis of the changes in certain circulatory indicators that were noted while the subjects were still horizontal. In our opinion, the changes described above are explained quite well from the standpoint of the peculiarities of vagosympathetic effect on the cardiovascular system. /238

Using comparative-physiology methods, D.A. Biryukov (1960) and D.U. Ermatova (1962) showed that animals whose ecology is characterized by a low level of motor activity (rabbits, rats) are distinguished by clear predominance of sympathetic tonus as compared with more mobile animals (hares, pigeons). In a study of humans, M.R. Mogdenovich (1957) established that systematic physical conditioning increases the parasympathetic influence on the

heart, slows the pulse, and lowers arterial pressure. On the whole, these authors regard parasympathetic tonus as an evolutionary factor that tends to perfect regulation of cardiac activity under the conditions of high motor activity. With this point of view in mind, we might conclude that the increases in pulse frequency and arterial pressure that were observed toward the end of hypodynamia were a result of reduced parasympathetic tonus owing to the restriction of the subjects' motor activity. In all probability, the daily physical loads imposed on the series III-V subjects were not enough to maintain the normal parasynpathetic influences on the heart. At the same time, it should be noted that the pulse-frequency and arterial-pressure shifts were nevertheless relatively modest in experimental series III.

To one degree or another, the various prophylactic measures used in the experiment helped maintain a level of orthostatic stability that was higher than that in series I (the control), although they were unable to prevent completely the development of orthostatic disturbances. The results obtained for the subjects in series III appear in the most favorable light. Although certain authors (Miller et al., 1965; Chase et al., 1966) are not inclined to regard physical exercising as an effective preventive measure against orthostatic disorders, the data obtained in this series of experiments are incontrovertible evidence to the contrary. The helpful influence of the physical exercises on tolerance to orthostatic disturbances was also noted by M.A. Cherepakhin (1968).

To judge from the results obtained on examination of the series II subjects, the use of drugs that have a tonic effect on the vegetative centers, brain cortex, cardiovascular system, and striated musculature was also fully justified, and prevented the development of collaptoid reactions in the orthostatic test.

The decrease in the prophylactic effect in the last two /239
series of experiments, where two types of physical conditioning were supplemented by the use of inflatable thigh cuffs and the drugs tested in series II, was somewhat unexpected. One possible explanation for this surprising result might be the higher degree of extensibility found in the vessels of the lower extremities when the femoral veins were periodically occluded as compared to the cases in which occlusion conditioning was not applied (series I-III). This creates the prerequisites for heavier depoting of blood in the lower extremities, with the natural detrimental effects on the nature of orthostatic stability. It appears that the occlusion-conditioning schedule used in series IV and V was not so effective as to prepare the organism for prolonged stagnation of blood in the lower half of the body and exclusion of some of it from the bloodstream. The results of occlusion conditioning are discussed in greater detail in another report (Voloshin, Pestov, Asyamolov, this collection).

It also appears appropriate to dwell briefly on the pathophysiology of the orthostatic disorders. From our point of view, the changes registered in orthostasis can be grouped according to the following criteria:

– shifts governed by position changes of the heart and the rotation of its electrical axis in the vertical position, which appear on electrocardiographic examination;

– changes governed by the reduced return of venous blood to the heart, as discerned in the development of stagnation effects in the lower extremities and reduced systolic volume;

– compensatory changes of a reflex nature, aimed at maintaining heart minute volume and capillary blood flow, which were evaluated from the data on pulse frequency, arterial pressure, vascular tone, and peripheral resistance;

– shifts governed by overloading of the heart, imperfect regulation of the heart, and deconditioning of the cardiovascular system. Shifts of this kind can be characterized by signs of development of cardiac insufficiency, myocardial ischemia, slower intracardiac conduction, and changes in the indicators to the contractile function of the heart (for example, the intrasystolic index, the myocardial tension index, the average rate of blood ejection, etc.).

The results of our study are consistent with contemporary notions as to the genesis of orthostatic disturbances under conditions that simulate weightlessness. They attest to the possibility of preventing the most severe of the orthostatic disturbances, and the collaptoid states in particular. However, it must be acknowledged that the use of the combined prophylactic measures in the experiment was still not effective enough to prevent the development of other signs of orthostatic instability. /240

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CHANGE IN LOAD-FACTOR TOLERANCE AFTER 70 DAYS OF HYPODYNAMIA

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ABSTRACT: Stability to the action of transverse g-forces was investigated in 12 subjects before and after a prolonged (70-day) confinement to bed. Overload tolerance was evaluated in terms of the maximum g-force at which the first signs of physiological-function disturbance made their appearance, and on the basis of shifts in the physiological reactions during and after action of the load factor. A distinct decrease in the tolerance to transversely directed g's was noted after the passive sojourn in bed. Use of drugs and physical exercises during hypodynamia was clearly helpful. The combination of prophylactic measures resulted in an increase in the maximum load factor tolerated after hypodynamia without any substantial decrease of over-all stability. In all cases, however, the physiological systems were more severely stressed under a given g-force after hypodynamia.

It has now been established by foreign and Soviet researchers that the functional capabilities of the various physiological systems are lower after imposition of hypodynamia under laboratory conditions (Kakurin, Tokarev, 1962; Kakurin et al., 1966; Vanyushina, 1963; Korobkov, 1961; Stoyda, 1965; Deitrick, 1948; Graveline, Barnard, 1966, and others). /241

The literature offers only occasional articles reporting studies of human tolerance of g-forces after hypodynamia. In our studies (Katovskaya, Simpura, Kakurin, 1963; 1965), we established that stability to transverse g's is lower after 15-20 days of hypodynamia. The extent of the tolerance change showed individual differences and averaged 2.0 units. Stronger reactions of the physiological systems to g-forces were also noted in these studies following hypodynamia of the indicated duration.

After 60 days of hypodynamia, g-force tolerance remained at about the same level as that of the 20th day in the horizontal position. The average stability decrease was 2.4 units (Kotovskaya, Vartbaronov, Simpura, 1967). Miller and Leverett (1965) studied tolerance to transverse g's in 22 subjects after 4 weeks of passive confinement to bed. The shifts in pulse frequency and

the state of the visual function under g-forces simulating re-entry of a Gemini spacecraft with a maximum of 10.6 g's served as the tolerance criterion. The authors were not successful in distinguishing reliable differences in the extent of the visual disturbances. After hypodynamia, however, pulse frequency increased at the peak load factor by an average of +33±20 beats/min as compared with the control spin.

The object of the present investigations was to study the influence of 70 days in the horizontal position with restricted mobility and various preventive measures on human tolerance to transversely directed load factors ($+G_x$).

Twelve subjects participated in the centrifuge tests in five series of experiments. The load-factor tests were conducted on a centrifuge with a 7.5-meter radius. The gradient of the load-factor increase was 0.2 units/sec. The subject's position in the seat was optimal from the standpoint of g-force tolerance. The slant angle of the seat back was 10°. Tolerance was evaluated from the largest load factor that could be tolerated and from the shifts in the organism's physiological reactions. The value of the disturbance actually attained was also taken into account. The basic criterion of attainment of the tolerance limit was the appearance of negative bradycardia on the EKG or, less frequently, respiratory and visual disturbances, which were usually combined with prolongation of the latent period of the motor response to light signals up to the point at which there was no response at all.

Recovery from the tolerance changes was followed until the initial tolerance had fully recovered (up to 1-2 months). The following indices were registered to evaluate the degree of the physiological reactions: the EKG (in the 3 Nebu leads), maximum pressure in the brachial artery and in the vessels of the upper arm, oscillations in the vessels of the fingers and ears, the pneumogram, pulmonary ventilation, and oxygen demand. All subjects were classified arbitrarily into three groups on the basis of the nature of the tolerance changes established: group I (2 subjects) — persons with substantially lowered stability. This group included the series I subjects. Group II (6 subjects) — individuals with small tolerance changes. This group included the subjects of experimental series II and III, where drugs and physical exercises were used separately during the 70-day confinement to the horizontal position. Group III (4 subjects) — individuals with no marked decrease in the over-all stability of the organism, with a slight increase in the maximum tolerable load factors. This group included the subjects of experimental series IV and V, in which combined preventive measures were taken. /242

The differences in the tolerance shifts between these groups were statistically reliable (error less than 0.05). Stability and the physiological reactions were therefore analyzed in terms of

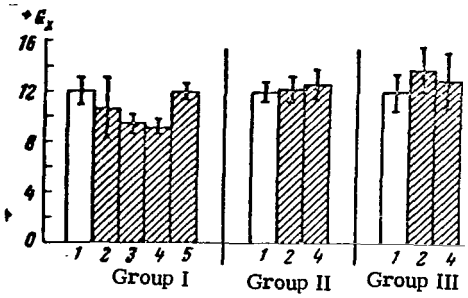

Figure. G-Tolerance Limits after Hypodynamia (Averaged data). Confidence Interval Calculated for T = = 2.0. 1) Initial background; 2) on 1st day- 3) on 17th day; 4) on 23rd-32nd days; 5) on 62nd day after hypodynamia.

these three groups (Fig. 3) [sic]. It was established that tolerance was distinctly lower in both subjects of group I after 70 days of passive existence in the horizontal position. Thus, on the 1st day after the end of hypodynamia, M-s showed a 3.2-unit decrease in tolerance. For the other subjects (A-n), even though the g-force reached had not changed, the degree of disturbance to the physiological reactions was considerably greater than during the background test. Beginning 30 minutes after the centrifuge was stopped, this subject also experienced pains behind his sternum and around his heart, and they persisted for more than 12 hours despite the therapeutic measures taken.

Subjectively, both subjects felt worse on subjection to the load factors after hypodynamia than they had initially. Retesting on the centrifuge 17 days after hypodynamia indicated that load-factor tolerance remained at the lowered level in the group I individuals. These stability shifts gradually levelled out, and two months later, the maximum tolerable g-force had practically reached its initial level in both subjects (Figure). Study of the cardiovascular system's response to g's indicated deterioration of its functional capabilities on the 1st day after the passive hypodynamia. Both group I subjects showed more pronounced tachycardia at the same g-factors (8-10 g's). The pulse rise on the 1st day after hypodynamia averaged +49 beats/min /243 (Table). Other hemodynamic indicators had also shifted substantially; there was a more distinct decrease in the oscillations of the finger and ear vessels and an increase in relative respiratory-wave amplitude. The recovery times of the various cardiovascular indicators during the aftereffect of centrifuging were considerably longer, at 75 minutes for M-s and 10 hours for K-n (as against 7 and 3 minutes, respectively, after the background spin).

The shifts in the respiratory and gas-exchange indicators in group I with increasing load factor also indicated a decrease in the organism's functional reserves after hypodynamia. Lowered pulmonary ventilation and oxygen demand were observed in both subjects. In this case, the deterioration of respiratory efficiency took the form of a reduction of respiratory volume. After application of the load factors, subject K-n showed an increase in oxygen deficit and a substantial decrease in recovery factor. In subject M-s, the smaller oxygen deficit after hypodynamia by

TABLE. CHANGE IN HEART FREQUENCY (beats/min) UNDER SUBJECTION TO 8-10-g LOAD FACTOR BEFORE AND AFTER 70-DAY HYPODYNAMIA (Averaged data)

Series	Number of subjects	Before hypodynamia			After hypodynamia							
		absolute level	absolute level after medication	difference	on 1st day		on days 17-20		on days 23 to 32		on 62nd day	
					absolute level	difference	absolute level	difference	absolute level	difference	absolute level	difference
I	2	123±2	—	—	172±4*	+49±4*	156±0*	+33±1*	123±9	0±8	123±9	0±8
II and III	6	108±4	—	—	143±6***	+35±4****	—	—	107±3	−1±2	—	—
IV and V	4	136±6	138±8	+1±4	161±8**	+24±6*****	—	—	148±11	+11±4	—	—

*Reliable difference from background value ($P > 0.999$).
**Reliable difference from background value ($P > 0.95$).
***Reliable difference from background value ($P > 0.999$) and series I data ($P > 0.99$).
****Reliable difference from background value ($P > 0.999$) and series I data ($P > 0.95$)
*****Reliable difference from background value ($P > 0.99$) and series I data ($P > 0.99$).

comparison with the background centrifuging was associated with a sharp drop in the g-factor that could be tolerated after hypodynamia (9.3 units). Under normal conditions, no oxygen deficit is observed under the action of "peak-type" load factors ranging up to 10 g's. After hypodynamia, on the other hand, this subject had an oxygen deficiency of 188 ml. Deterioration of gas exchange is also indicated in this case by the lower recovery factor.

The shifts in g-force tolerance were insignificant on the 1st day of hypodynamia and a month after its conclusion in the group II subjects, and did not exceed $\pm$0.8 unit (Fig. 1) [sic]. In one case (subject B-y), the tolerance limit could not be determined immediately after hypodynamia. After a month, however, no substantial differences from the initial level could be detected in this subject's load-factor tolerance. Thus, the separate use of the medication and the physical-exercise program during 70 days of hypodynamia prevented substantial loss of load-factor tolerance. /245

At the same time, we should note that the shifts in the physiological reactions in response to g-forces on the 1st day after hypodynamia differed little in general trend between groups II and I, although the pulse-frequency rise was somewhat smaller (+35 beats/min) and also differed reliably from the increase in cardiac frequency in the persons who had not exercised in bed (Table). The extent of the amplitude decrease in the oscillations of the finger vessels and the increase in the respiratory waves did not differ reliably from the group I data.

The time for the cardiovascular indicators to recover increased in only two of five cases among the group II individuals. During the "runup" on the centrifuge on the 1st day after hypodynamia, all subjects of this group (except for G-y) showed lowered pulmonary ventilation and a decrease in oxygen demand. These shifts were definitely less distinct than in the group I individuals. As the centrifuge was decelerated, and during the aftereffect, the shifts in the respiratory and gas-exchange indicators showed substantial individual scatter. However, a decrease in repiratory volume was noted in only three subjects out of the 6. The increase in oxygen demand and oxygen deficit and the decrease in recovery factor depended both on the applied g-force (subjects B-y, M-k, K-v) and on the preceding hypodynamia (subjects B-k, G-y). Only in one subject (G-y) did we note substantial improvement of respiratory efficiency and oxygen-regime regulation under the action of the load factor. A month after hypodynamia, the respiratory indicators showed practically no differences from the background data.

Among the group III subjects, for whom combined prophylactic measures had been taken during hypodynamia, general tolerance of load factors had not changed substantially, and the maximum tolerated g's were even found to be higher than in the initial test

(figure). One month after the end of hypodynamia, the tolerance level differed little from the original value for all of the subjects.

When the original g-factors were reached the day after hypodynamia, simple tachycardia was found to be more pronounced than in the control studies in all cases, but still below the group I value. The average increase was +24 beats/min (see Table). The shifts in other hemodynamic indicators after hypodynamia differed little from the data for groups I and II. As for respiration and gas exchange, an increase in respiratory volume and no decrease in oxygen demand were noted as the g-force was increased. In two cases (subjects B-v and F-v), oxygen demand even increased. It /246
increased as the centrifuge was decelerated, and during the aftereffect oxygen deficit increased and the recovery factor declined. A month after termination of hypodynamia, these indices to the physiological reactions had approached their initial level.

Additional control experiments were performed on individuals of this group, with determination of individual load-factor tolerance after administration of medications. These preparations were given in the same doses as during hypodynamia, but with maintenance of normal motor activity. It was established that no reliable tolerance shifts could be observed after administration of the drugs. The extent of the physiological reactions was approximately the same as in the control. It can be assumed on the basis of these observations that the helpful effect of the drugs in series III was probably due to their therapeutic action on an organism that had been weakened by hypodynamia. This fact should probably also be considered in explaining the increase in g-force tolerance limit when combined prophylactic measures were taken against the hypodynamic disturbances (in series IV and V).

As we examine the data obtained, our attention is drawn to the fact that even the increase in the load-factor tolerance limit in group III after 70 days in bed is accompanied by heavier stressing of the organism's cardiovascular and respiratory compensatory mechanisms. In our opinion, this circumstance indicates that all of the prophylactic measures taken during the 70 days of hypodynamia act selectively in the last analysis and do not completely eliminate the state of deconditioning of the basic physiological systems that are affected when a man spends a long time in bed.

CONCLUSIONS

1. Prolonged (70-day) confinement of a man to the horizontal position with mobility restrictions lowers his tolerance for transversely directed g-forces. The tolerance decrease may persist for more than one month after hypodynamia is terminated.

2. The use of either drugs or physical exercises produces an obvious helpful effect, although it does not provide for full

preservation of the organism's general tolerance to load factors.

3. Use of combined prophylactic measures in the form of physical exervises, drugs, and inflatable cuffs on the thighs was definitely more effective than the use of each method by itself. /247

4. When the original g-force values were reached after hypodynamia, all subjects showed more severe functional stressing of the organism's physiological systems than in the initial tests.

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BASIC RESULTS FROM STUDIES OF THE INFLUENCE OF 70-DAY HYPODYNAMIA ON THE HUMAN ORGANISM

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T.T. Dzhamgarov, A.G. Panov, I.I. Ivanov,
and I.D. Pestov

ABSTRACT: The results obtained in the course of the experiment are examined in juxtaposition to the expected consequences of hypodynamia, which are presented in diagram form. Certain new aspects of the influence of prolonged bedrest on the organism were brought to light during the study: a decrease in immunological resistance, certain disturbances to the mental functions, the development of trophic changes in the myocardium, changes in reactivity to medication, etc. The specifically designed physical-conditioning procedures were found to be relatively most effective in mitigating the detrimental effect of hypodynamia.

The following questions were studied in experiments in which 16 subjects spent 70 days confined to bed, in accordance with the basic project objectives formulated in the introductory articles of this collection:

– the phenomenology of the shifts governed by prolonged limitation of mobility with restriction to the horizontal position;

– closer examination of the mechanisms by which these shifts /248
arise during 70 days of simulated weightlessness;

– the possibility of mitigating the adverse effects of prolonged hypodynamia by the use of drugs, physical exercise, and two different prophylactic complexes that included drugs, occlusion cuffs, and two varieties of physical conditioning.

The experience that had been accumulated in experimental study of hypodynamia as a state that simulates weightlessness to a certain degree (Buyanov et al., 1966; Graveline, 1962; Lamb et /249
al., 1964) made it possible to concentrate attention on the shifts that are now regarded as determining in the pathogenesis of the disorders that arise during weightlessness.

Using the scheme given below, an attempt was made to generalize on the experimental data obtained by Soviet and foreign authors under simulated-weightlessness conditions, to single out the

EXPECTED CONSEQUENCES OF PROLONGED CONFINEMENT TO BED

Primary Reactions

Hypodynamia due to reduced gravitational load on supporting structures and restriction of mobility.....

Lowered hydrostatic pressure of blood and absence of hydrostatic-pressure fluctuations in vessels

Changes in activity of afferent systems

Mediated Reactions

1. Absence of static tension of postural musculature
2. Lowered energy metabolism
3. Negative nitrogen balance
4. Atrophy of muscles, reduction of muscular mass, decreased strength and endurance
5. Decrease in body weight at expense of muscle component
6. Decalcification of bones
7. Excretion of creatinine with urine
8. Loss of motor habits
9. Deconditioning of cardiovascular system
10. Redistribution of blood toward thorax
11. Increased diuresis
12. Plasma loss and lowered circulating-blood volume
13. Decrease in body weight due to dehydration
14. Deconditioning of cardiovascular system with respect to hydrostatic factor
15. Lowering of interoceptive afferentation, including that from vascular-bed receptors
16. Change in proprioceptive afferentation (muscle-joint sensation)
17. Psychological stress
18. Disturbed sleep
19. Readjustment of reflex regulation of vegetative and somatic functions
20. Change in humoral regulatory link

Resultant Effects

4-8-9-13-14-16-19-20
Change in physical efficiency and movement coordination

4-9-14-15-16-19-20
Lowered tolerance of transverse g-forces

1-4-12-13-14-15-19-20
Lower orthostatic stability

most important cause-and-effect relationships between the primary and mediated reactions, and to trace certain aspects of the shaping of the most important resultant effects. The experience of other authors who have tried to systematize data on the pathogenesis of the disorders that arise during real or simulated weightlessness were taken into account in compiling this diagram (Ch. Wunder, 1965; Kas'yan, Kopanev, 1965; Papin, et al., 1967). Needless to say, any attempt to simplify the complex process of regulation of the organism's internal medium under altered conditions must be regarded as a mere formal device that is convenient for isolation of the relatively more important relationships.

In our opinion, it is also expedient to systematize the experimental material collected in this study on the principle reflected in the above scheme. It would then be possible to compare it with the most commonly held conceptions, bring to light certain new aspects of the pathogenesis of hypodynamic disturbances, and distinguish differences of degree in the various symptoms, which might possibly have a bearing on longer hypodynamia experiments.

It should be remarked that the results of the present study are, on the whole, in agreement with the idea that hypodynamic and hydrostatic factors are prominent in the genesis of the disturbances governed by the weightlessness model used in this experiment. The experimentally established facts include a reduction of energy metabolism under the conditions of bed confinement (Mikhasev et al., this collection), the appearance of a negative nitrogen balance (Seregin et al., this collection), a decrease in muscular mass and the muscular strength and endurance indicators (A.V. Yeremin et al., A.G. Panov et al.), deconditioning of the cardiovascular system with respect to physical exertion (A.V. Yeremin et al.), and redistribution of the blood toward the lower half of the body (V.V. Simonenko). There was also a loss of body weight due to preferential loss of the muscle component and a slight increase in the fatty component (A.G. Zhdanova), increased excretion of calcium with the urine (M.S. Seregin et al.), resulting in the development of bone decalcification (I.G. Krasnykh). Other observations included readjustment of the neurohumoral regulation of vegetative and somatic functions, for example on the basis of cardiovascular data (M.I. Tishchenko et al., A.D. Voskresenskiy et al.) and data on neurological status (A.G. Panov et al., G.S. Kalin, V.G. Terent'yev). /250

Nonspecific central-nervous-system changes were observed to develop, but they had no influence on sensomotor functions or the rate of information processing by the subjects (G.D. Yefimenko, V.L. Marishchuk).

In the final analysis, the above shifts resulted in a marked lowering of the subjects' orthostatic stability (I.D. Pestov et al.), their tolerance to transverse load factors (A.R. Kotovskaya

et al.), and physical fitness for work (A.V. Yeremin et al.).

Along with these changes in the state of the organism, which could be predicted quite accurately on the basis of available literature material, certain new aspects of the influence of prolonged bedrest on man were brought to light in the course of this study.

Among them, we might cite data from the neurological study (development of interhemispheric asymmetry as a result of dextral pyramidal insufficiency (A.G. Panov et al.), clearly manifested disturbances of movement coordination (V.S. Gurfinkel' et al.), the psychic functions (V.P. Bogachenko, V.L. Marishchuk et al.), readjustment of the vestibular function (K.L. Khilov et al.), development of relative predominance of sympathetic over parasympathetic tonus (I.D. Pestov et al.; V.V. Simonenko) with a tendency to decay of the respiratory periodicity of cardiac rhythm (A.D. Voskresenskiy et al.). Further, the cardiovascular system showed the development of trophic changes in the myocardium, disturbance of intracardiac conduction, certain shifts in the phase structure of the cardiac cycle (A.D. Voskresenskiy et al.) and a decrease in the elastic properties of blood vessels in the lower extremities (V.G. Voloshin et al.).

Lowered coagulability of the blood (Ye.I. Dorokhova), increased alkaline-phosphatase activity in the blood serum as a result of the development of destructive changes in the bones (I.I. Ivanov et al.), and loss of appetite and intestinal motor function (P.A. Sorokin et al.) were also reported. Establishment of changes in resistance to infection, especially as they result from lowered leucocyte phagocytic activity (B.A. Chukhlovin, S.A. Burov), and the change in over-all reactivity, for example to medications (P.V. Vasil'yev, B.Yu. Lapinskaya) were extremely important. Increased activity of conditionally pathogenic and saprophytic automicroflora and activation of latent infection were noted among the results; they led to a rather high percentage incidence of illness among the subjects, the course of which was quite peculiar, sluggish, and unresponsive to treatment (P.A. Sorokin et al.). /251

Another important factor was the establishment of phases in the development of manifest symptomatics (P.A. Sorokin et al.; A. G. Panov et al.; K.L. Khilov et al. and others), apparently characterizing an undulatory process of readapting the functions to the new level of regulation. To judge from various indicators, the recovery period lasts from one (M.I. Tishchenko et al.) to two or three months (G.S. Kalin, V.G. Terent'yev, A.V. Beregovkin et al.).

These peculiarities of the course taken by hypodynamic status represent an important supplement to notions as to the nature of the shifts produced in the organism by the weightlessness-simulating factors.

Special attention should be given to the results obtained on the shifts with a bearing on water-metabolism regulation under the conditions of lowered hydrostatic blood pressure. As follows from the scheme given earlier, we should be justified in expecting redistribution of the blood toward the thorax under the conditions of bed confinement, with a subsequent increase in diuresis and a decrease in circulating blood volume. However, this relationship was not clearly in evidence (A.P. Pekshev). In the studies made in the 2nd, 4th, and 8th weeks of confinement to bed, the tendency actually recorded was instead toward a certain increase in circulating blood volume (series II and III). On the other hand, use of agencies specifically designed to maintain the original circulating blood volume (occlusion conditioning in series IV and V) unexpectedly lowered it. This apparently paradoxical effect undoubtedly requires further experimental evaluation. At the same time, it should be noted that the water-metabolism shifts and the variations of plasma volume are quite transitory and, according to Vogt et al. (1967), culminate during the first few days of confinement to bed. The subsequent trend in water-balance regulation, however, has been studied quite inadequately. Interestingly, an increase in plasma volume instead of the expected decrease has been reported in a number of cases in cosmonauts who have just completed spaceflights (Fischer et al., 1967).

As we have noted, a number of prophylactic principles were tested during the studies against the disorders that arise during simulation of weightlessness. While they are important in their purely applicational aspect, these studies also contributed to better understanding of the pathogenetic mechanisms behind the hypodynamic status. Thus, it was found that the disorders that arise from prolonged confinement to bed are best controlled by a specifically designed physical-exercise program (A.V. Yeremin et al.). Even though the effect was less than complete again in this case, it indicates that hypodynamia is one of the basic causes of the adverse reactions that appear during simulation of weightlessness and that a rationally constructed program of motor activity offers promise as a preventive against these reactions. /252

Use of occlusion conditioning with the object of simulating blood hydrostatic pressure (V.G. Voloshin et al.) did not result in a full evaluation of the hydrostatic factor in the genesis of the disturbances described above. It appears that its use did have some effect. It was manifested in a smoother course of the period of hypodynamia itself and, which is particularly important, a relatively higher tolerance of transverse g-forces at the end of hypodynamia as compared with the other series (A.R. Kotovskaya et al.). However, the basic effects that were hoped for in the use of occlusion conditioning were not registered. As we have noted, the circulating blood volume did not increase, but decreased when it was applied (A.P. Pekshev).

Occlusion conditioning was similarly ineffective as regards orthostatic stability (I.D. Pestov et al.), although this may be due to defects in the application of this conditioning.

The use of drugs (amphetamine, caffeine, securinine) that have a tonic effect on the brain cortex, subcortical vegetative centers, the spinal cord, the heart, and the striated musculature (P.V. Vasil'yev, B.Yu. Lapinskaya) was not, of course, intended to prevent the entire spectrum of hypodynamic disturbances. However, their use during periods preceding stress disturbances (load factors, orthostatic tests) was found to be justified and indicates the importance of the neuroreflexive regulatory link in improving the compensatory possibilities of the organism.

It is, of course, impossible to cover all aspects of the problem within the framework of this article. It has been concerned only with the most substantial results of the completed study — in particular, those that provide a basis for certain additions to the pathogenesis chart of the disturbances that arise during confinement to bed. It is our view that the most important of these additions should be the changes in immunological resistance. These changes appear to be extremely important from the standpoint of the prospects for long spaceflights. There would appear to be every reason for concentrating efforts at this time on determination of the causes of precisely these changes and a search for effective preventive measures against them. Concurrently, research should also be continued on more effective means of preventing disturbances on the part of the mental functions, cardiovascular system, supporting muscular apparatus, and other /253
systems of the organism with the object of keeping the cosmonaut at the required level of working efficiency under the conditions of a long flight and increasing his tolerance of gravitational forces (g-forces, orthostasis) on his return to the earth.

It appears that the results obtained from study of the effects produced in healthy young individuals who are confined to bed for long periods may also be helpful in clinical practice. For example, they might be used to differentiate certain consequences of bed confinement itself from the general picture of the clinical course taken by the disease, so that the necessary measures could then be taken to control these side effects.

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